Chemical Engineering Course Pack

Fall 2020

CHEE 200: Chemical Engineering Principles 1

Offered by:

ChESS

Chemical Engineering Students' Society

CHEE 200: Chemical Engineering Principles 1

Dear U1s,

This course pack contains an accumulated trove of past midterms and finals for this course, all to help you study for CHEE 200. Hopefully, this course pack proves to be a great boon to you all, helping you both learn the material and the types of questions you can expect for this course. Anecdotally, this course pack is often considered to be the most helpful of all, as it helps ease the transition of students into how chemical engineering courses are taught and tested. However, this course pack is anything but a be-all end-all. You have class and a textbook to consult first before anything found here.

Moreover, online classes will necessitate changes to how the course is delivered. As I'm sure you are all aware, COVID-19 has left an indelible mark on all of education. The transition online has, simply put, changed the game. On the positive side, that means that we can now make these course packs readily accessible to everyone through MyCourses and the ChESS website. On the negative side, studying the traditionally given exams of past years will likely be less useful for the upcoming, online semester.

All this is to say that this course pack comes with a major caveat:

Much of the material found in here is outdated on account of online classes. Moreover, any of these past exams may contain incorrect answers, some past exams may also contain questions with errors. This course pack is only made to help you guys, and we don't know exactly how useful it will be.

Regardless, I know I can speak for everyone on ChESS when I say this: entering the engineering discipline - especially in the midst of a global pandemic - is tough, but we believe in you guys. What we study isn't easy, but you wouldn't be here if it was. Moreover, if at any point during the semester things become overwhelming or you feel you are struggling with mental health, please feel free to reach out to not only the Chemical Engineering Equity and Mental Health representative, but also to any number of mental health services that work either together or separately from McGill, such as the Wellness Hub. Not to sound too corny, but you guys are the future of this discipline, and I know both professors and upper year students like myself believe in you!

Furthermore, keep an eye out for online ChESS activities. We are doing our best to adapt to all of the changes brought about by COVID-19, so we have a lot of exciting new events and initiatives we are hoping to roll out!

Kind regards and stay safe everyone,

Gregory Brock

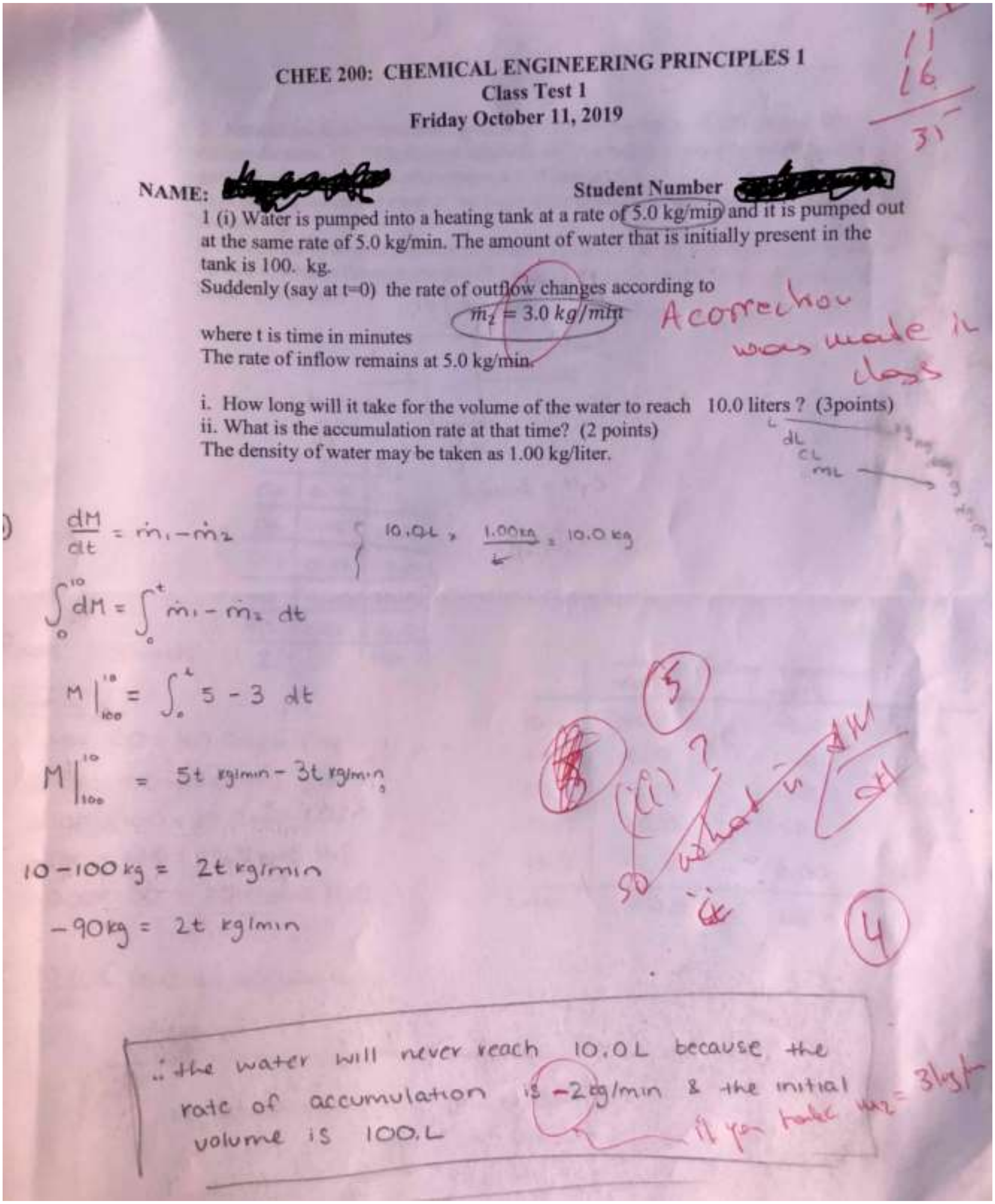
ChESS VP Academic 2020-2021

Contents

This course pack has material from multiple different course changes. As a result, there are tests, midterms, quizzes, etc. that each cover a different amount of material, are cumulative vs. noncumulative, and have many other differences as well. We provide the most recent exams at the beginning of this course pack as those will be most valuable for the course. However, when studying using older tests, make sure to check the date at which that older test was administered. If it's relatively close to the date of the test you will be given in class, it will likely cover somewhat similar material. Again keep in mind that the order in which material was delivered over the semester may have also changed as well though.

2019

Test 1



11

16

31

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1
Class Test 1
Friday October 11, 2019

NAME: [redacted] **Student Number** [redacted]

1 (i) Water is pumped into a heating tank at a rate of 5.0 kg/min and it is pumped out at the same rate of 5.0 kg/min. The amount of water that is initially present in the tank is 100. kg.
Suddenly (say at t=0) the rate of outflow changes according to

$$\dot{m}_2 = 3.0\ kg/min$$

where t is time in minutes
The rate of inflow remains at 5.0 kg/min.

A correction was made in class

i. How long will it take for the volume of the water to reach 10.0 liters ? (3points)
ii. What is the accumulation rate at that time? (2 points)
The density of water may be taken as 1.00 kg/liter.

dL
cL
mL

$$\frac{dM}{dt} = \dot{m}_1 - \dot{m}_2$$

$$10.0L \times \frac{1.00kg}{L} = 10.0\ kg$$

$$\int_0^{10} dM = \int_0^t \dot{m}_1 - \dot{m}_2\ dt$$

$$M\Big|_{100}^{10} = \int_0^t 5 - 3\ dt$$

$$M\Big|_{100}^{10} = 5t\ kg/min - 3t\ kg/min\Big|_0$$

$$10 - 100\ kg = 2t\ kg/min$$

$$-90kg = 2t\ kg/min$$

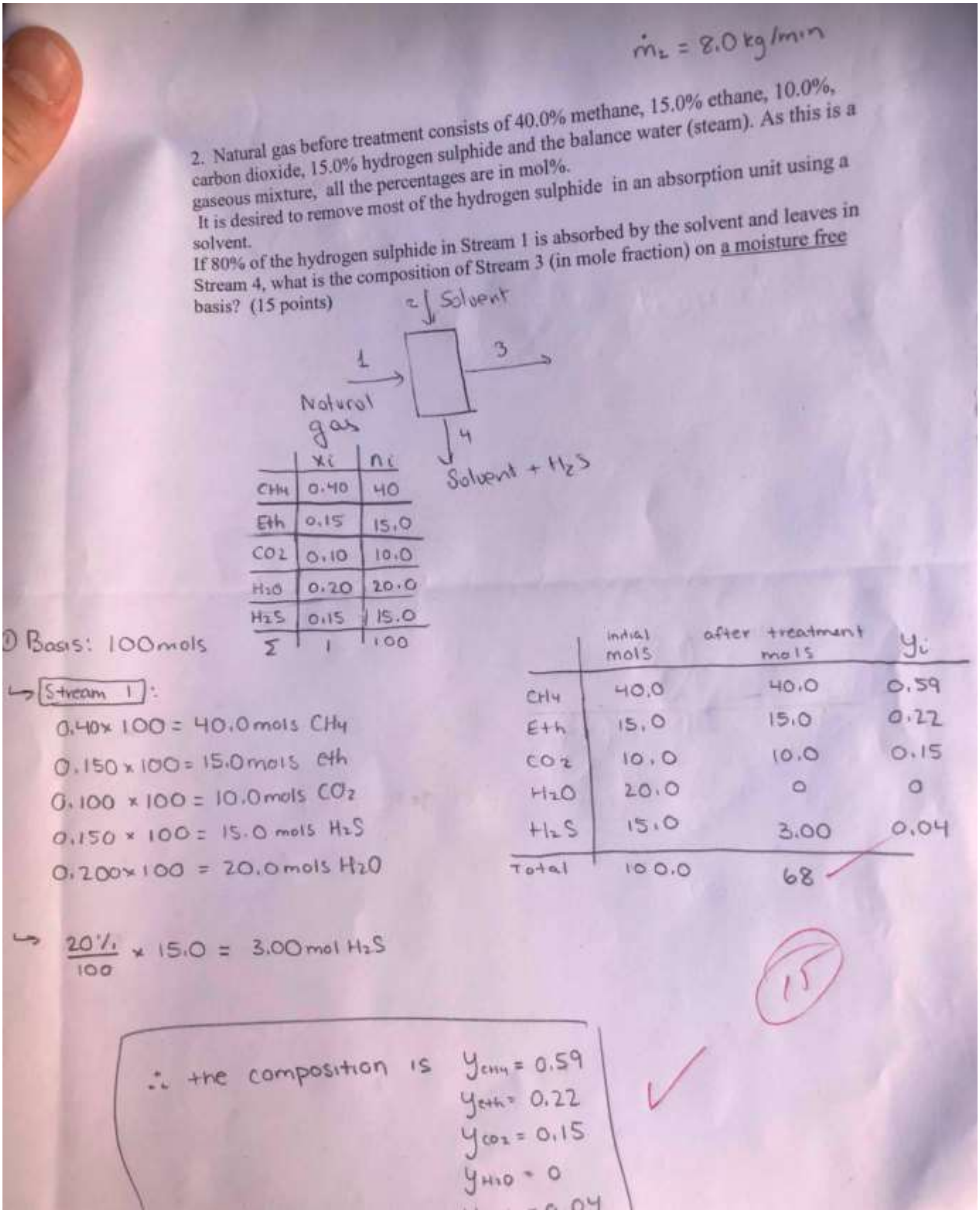
5

(ii) ? so what is $\frac{dM}{dt}$

4

∴ the water will never reach 10.0L because the rate of accumulation is −2kg/min & the initial volume is 100.L

if you take $\dot{m}_2$ = 3kg/min



$\dot{m}_2 = 8.0$ kg/min

2. Natural gas before treatment consists of 40.0% methane, 15.0% ethane, 10.0%, carbon dioxide, 15.0% hydrogen sulphide and the balance water (steam). As this is a gaseous mixture, all the percentages are in mol%.
It is desired to remove most of the hydrogen sulphide in an absorption unit using a solvent.
If 80% of the hydrogen sulphide in Stream 1 is absorbed by the solvent and leaves in Stream 4, what is the composition of Stream 3 (in mole fraction) on <u>a moisture free</u> basis? (15 points)

	x_i	n_i
CH_4	0.40	40
Eth	0.15	15.0
CO_2	0.10	10.0
H_2O	0.20	20.0
H_2S	0.15	15.0
Σ	1	100

① Basis: 100 mols

↳ $\boxed{\text{Stream 1}}$:

$0.40 \times 100 = 40.0$ mols CH_4
$0.150 \times 100 = 15.0$ mols eth
$0.100 \times 100 = 10.0$ mols CO_2
$0.150 \times 100 = 15.0$ mols H_2S
$0.200 \times 100 = 20.0$ mols H_2O

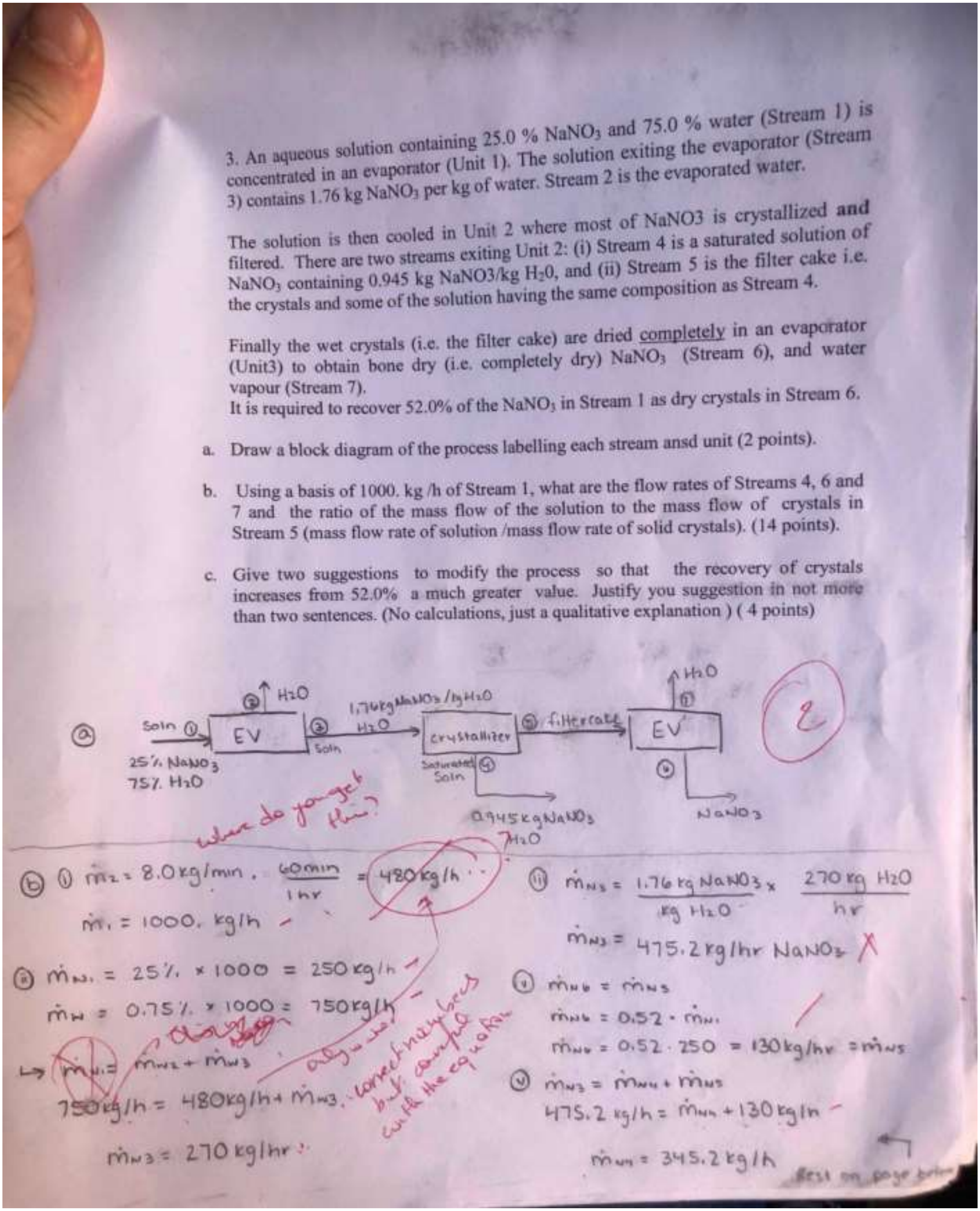
	initial mols	after treatment mols	y_i
CH_4	40.0	40.0	0.59
Eth	15.0	15.0	0.22
CO_2	10.0	10.0	0.15
H_2O	20.0	0	0
H_2S	15.0	3.00	0.04
Total	100.0	68	

↳ $\frac{20\%}{100} \times 15.0 = 3.00$ mol H_2S

15

∴ the composition is
$y_{CH_4} = 0.59$
$y_{eth} = 0.22$
$y_{CO_2} = 0.15$
$y_{H_2O} = 0$
= 0.04

✓



3. An aqueous solution containing 25.0 % $NaNO_3$ and 75.0 % water (Stream 1) is concentrated in an evaporator (Unit 1). The solution exiting the evaporator (Stream 3) contains 1.76 kg $NaNO_3$ per kg of water. Stream 2 is the evaporated water.

The solution is then cooled in Unit 2 where most of NaNO3 is crystallized **and** filtered. There are two streams exiting Unit 2: (i) Stream 4 is a saturated solution of $NaNO_3$ containing 0.945 kg NaNO3/kg H_20, and (ii) Stream 5 is the filter cake i.e. the crystals and some of the solution having the same composition as Stream 4.

Finally the wet crystals (i.e. the filter cake) are dried completely in an evaporator (Unit3) to obtain bone dry (i.e. completely dry) $NaNO_3$ (Stream 6), and water vapour (Stream 7).
It is required to recover 52.0% of the $NaNO_3$ in Stream 1 as dry crystals in Stream 6.

a. Draw a block diagram of the process labelling each stream ansd unit (2 points).

b. Using a basis of 1000. kg /h of Stream 1, what are the flow rates of Streams 4, 6 and 7 and the ratio of the mass flow of the solution to the mass flow of crystals in Stream 5 (mass flow rate of solution /mass flow rate of solid crystals). (14 points).

c. Give two suggestions to modify the process so that the recovery of crystals increases from 52.0% a much greater value. Justify you suggestion in not more than two sentences. (No calculations, just a qualitative explanation) (4 points)

ⓑ ① $\dot{m}_2 = 8.0$ kg/min $\cdot \frac{60 \text{ min}}{1 \text{ hr}} = \cancel{480 \text{ kg/h}}$

$\dot{m}_1 = 1000.$ kg/h

ⓘⓘ $\dot{m}_{N1} = 25\% \times 1000 = 250$ kg/h

$\dot{m}_W = 0.75\% \times 1000 = 750$ kg/h

change

↳ $\cancel{\dot{m}_{W1}} = \dot{m}_{W2} + \dot{m}_{W3}$

750 kg/h = 480 kg/h + $\dot{m}_{W3}$

$\dot{m}_{W3} = 270$ kg/hr

only [illegible] correct numbers but complete with the equation

ⓘⓘⓘ $\dot{m}_{N3} = \frac{1.76 \text{ kg } NaNO_3}{\text{kg } H_2O} \times \frac{270 \text{ kg } H_2O}{\text{hr}}$

$\dot{m}_{N3} = 475.2$ kg/hr $NaNO_3$ ✗

ⓘⓥ $\dot{m}_{N6} = \dot{m}_{N5}$

$\dot{m}_{N6} = 0.52 \cdot \dot{m}_{N1}$

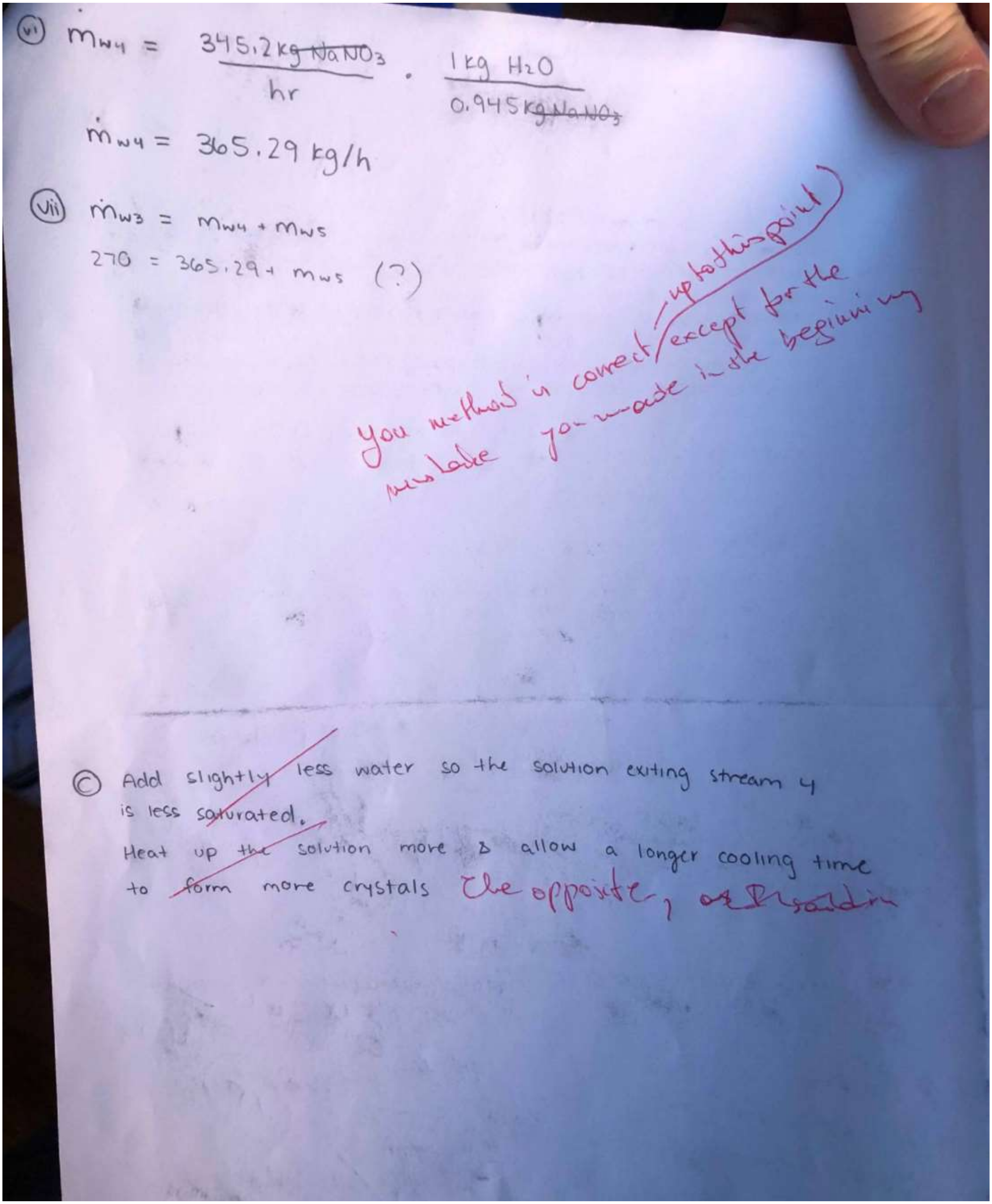
$\dot{m}_{N6} = 0.52 \cdot 250 = 130$ kg/hr $= \dot{m}_{N5}$

ⓥ $\dot{m}_{N3} = \dot{m}_{N4} + \dot{m}_{N5}$

475.2 kg/h = $\dot{m}_{N4}$ + 130 kg/h

$\dot{m}_{N4} = 345.2$ kg/h

Rest on page below



(vi) $\dot{m}_{w4} = \frac{345.2 \text{ kg } \cancel{\text{NaNO}_3}}{\text{hr}} \cdot \frac{1 \text{ kg H}_2\text{O}}{0.945 \text{ kg } \cancel{\text{NaNO}_3}}$

$\dot{m}_{w4} = 365.29 \text{ kg/h}$

(vii) $\dot{m}_{w3} = m_{w4} + m_{w5}$

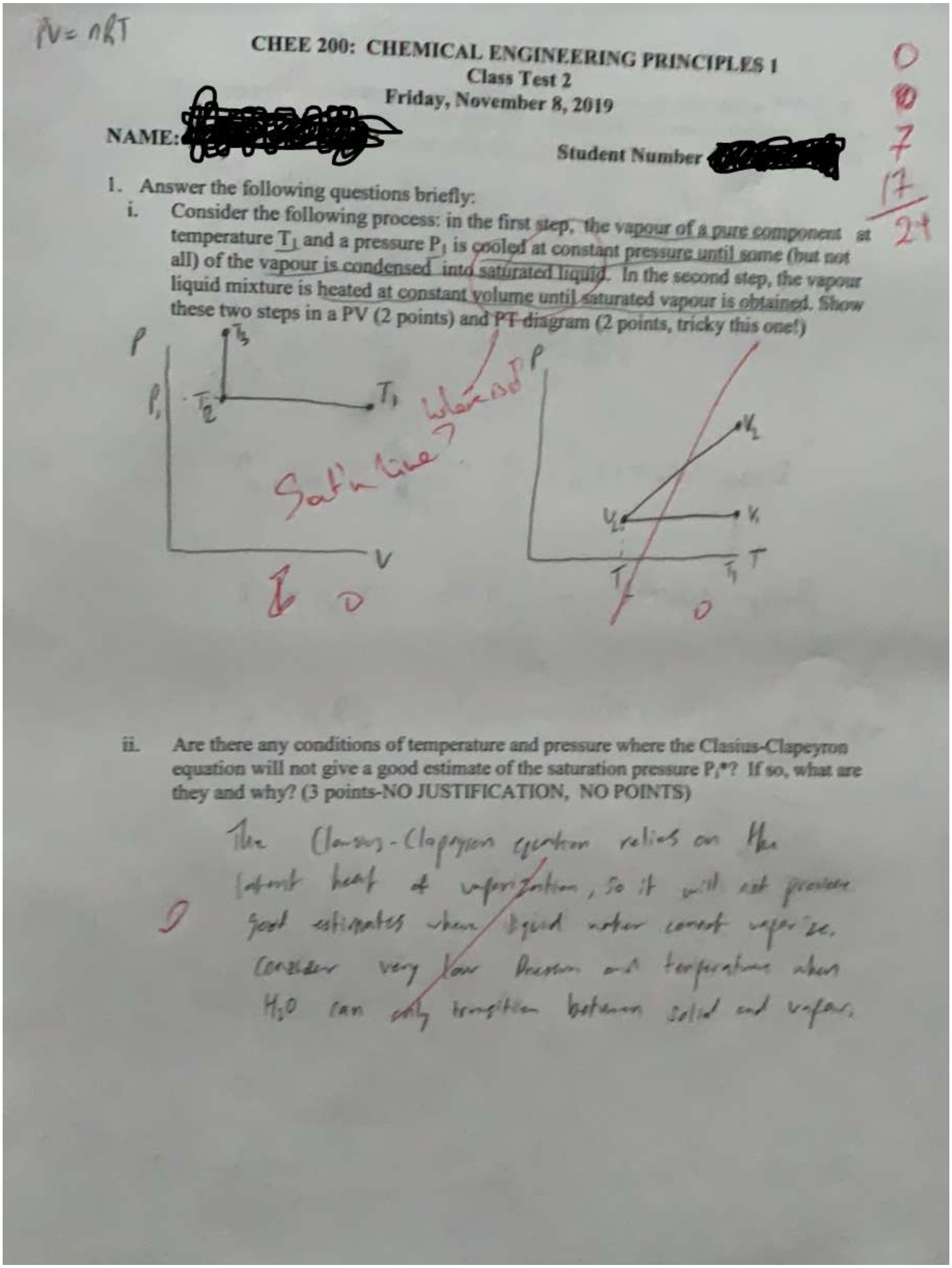
$270 = 365.29 + m_{w5}$ (?)

you method is correct up to this point except for the mistake you made in the beginning

© Add slightly less water so the solution exiting stream 4 is less saturated.

Heat up the solution more & allow a longer cooling time to form more crystals The opposite, as I said in

Test 2



$PV = nRT$

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1
Class Test 2
Friday, November 8, 2019

NAME: [redacted]

Student Number [redacted]

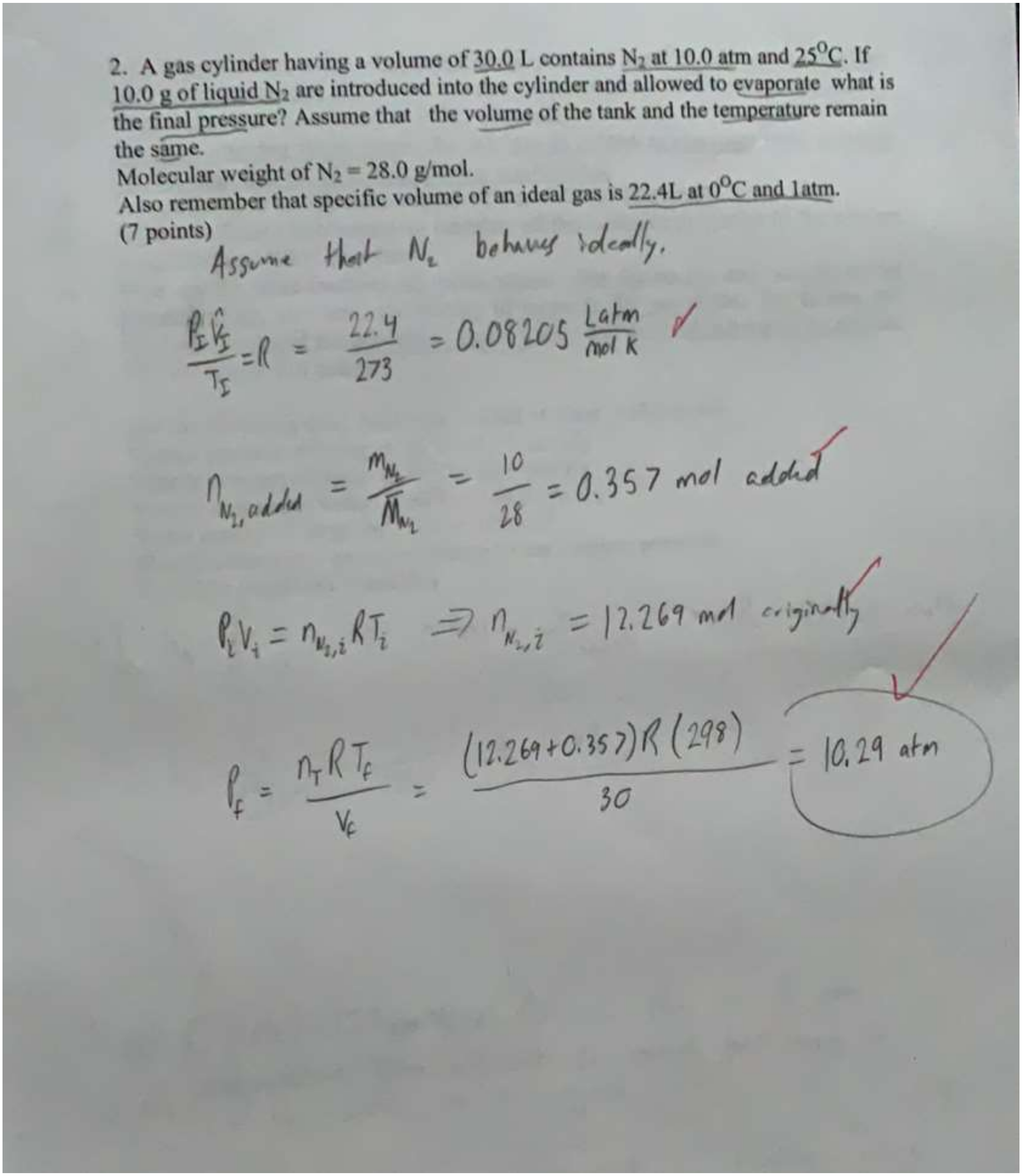
0
0
7
17/24

1. Answer the following questions briefly:
   i. Consider the following process: in the first step, the vapour of a pure component at temperature T_1 and a pressure P_1 is cooled at constant pressure until some (but not all) of the vapour is condensed into saturated liquid. In the second step, the vapour liquid mixture is heated at constant volume until saturated vapour is obtained. Show these two steps in a PV (2 points) and PT diagram (2 points, tricky this one!)

   ii. Are there any conditions of temperature and pressure where the Clasius-Clapeyron equation will not give a good estimate of the saturation pressure P_i^*? If so, what are they and why? (3 points-NO JUSTIFICATION, NO POINTS)

The Clausius-Clapeyron equation relies on the latent heat of vaporization, so it will not provide good estimates when liquid water cannot vaporize. Consider very low pressure and temperature when H_2O can only transition between solid and vapor.

0



2. A gas cylinder having a volume of 30.0 L contains N_2 at 10.0 atm and 25°C. If 10.0 g of liquid N_2 are introduced into the cylinder and allowed to evaporate what is the final pressure? Assume that the volume of the tank and the temperature remain the same.

Molecular weight of N_2 = 28.0 g/mol.

Also remember that specific volume of an ideal gas is 22.4L at 0°C and 1atm.

(7 points)

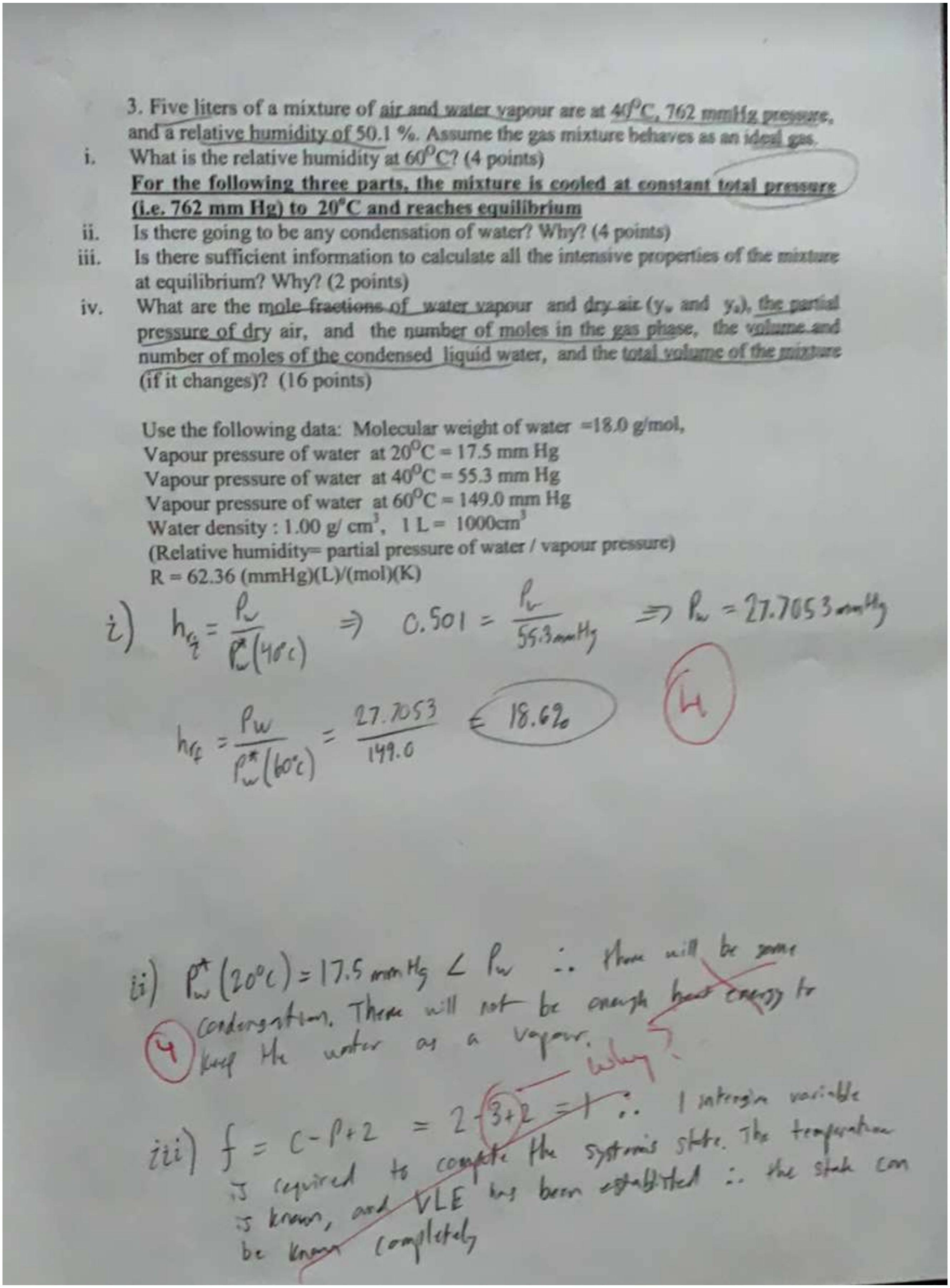
Assume that N_2 behaves ideally.

$$\frac{P_I \hat{V}_I}{T_I} = R = \frac{22.4}{273} = 0.08205 \ \frac{L\,atm}{mol\,K} \ ✓$$

$$n_{N_2,added} = \frac{m_{N_2}}{\bar{M}_{N_2}} = \frac{10}{28} = 0.357 \text{ mol added} \ ✓$$

$$P_i V_i = n_{N_2,i} R T_i \Rightarrow n_{N_2,i} = 12.269 \text{ mol originally} \ ✓$$

$$P_f = \frac{n_T R T_f}{V_f} = \frac{(12.269+0.357)R(298)}{30} \boxed{= 10.29 \text{ atm}} \ ✓$$



3. Five liters of a mixture of air and water vapour are at 40°C, 762 mmHg pressure, and a relative humidity of 50.1 %. Assume the gas mixture behaves as an ideal gas.

i. What is the relative humidity at 60°C? (4 points)

For the following three parts, the mixture is cooled at constant total pressure (i.e. 762 mm Hg) to 20°C and reaches equilibrium

ii. Is there going to be any condensation of water? Why? (4 points)

iii. Is there sufficient information to calculate all the intensive properties of the mixture at equilibrium? Why? (2 points)

iv. What are the mole fractions of water vapour and dry air (y_w and y_a), the partial pressure of dry air, and the number of moles in the gas phase, the volume and number of moles of the condensed liquid water, and the total volume of the mixture (if it changes)? (16 points)

Use the following data: Molecular weight of water =18.0 g/mol,
Vapour pressure of water at 20°C = 17.5 mm Hg
Vapour pressure of water at 40°C = 55.3 mm Hg
Vapour pressure of water at 60°C = 149.0 mm Hg
Water density : 1.00 g/ cm^3, 1 L = 1000cm^3
(Relative humidity= partial pressure of water / vapour pressure)
R = 62.36 (mmHg)(L)/(mol)(K)

i) $h_{r_i} = \frac{P_w}{P_w^*(40°c)} \Rightarrow 0.501 = \frac{P_w}{55.3\,\text{mmHg}} \Rightarrow P_w = 27.7053\,\text{mmHg}$

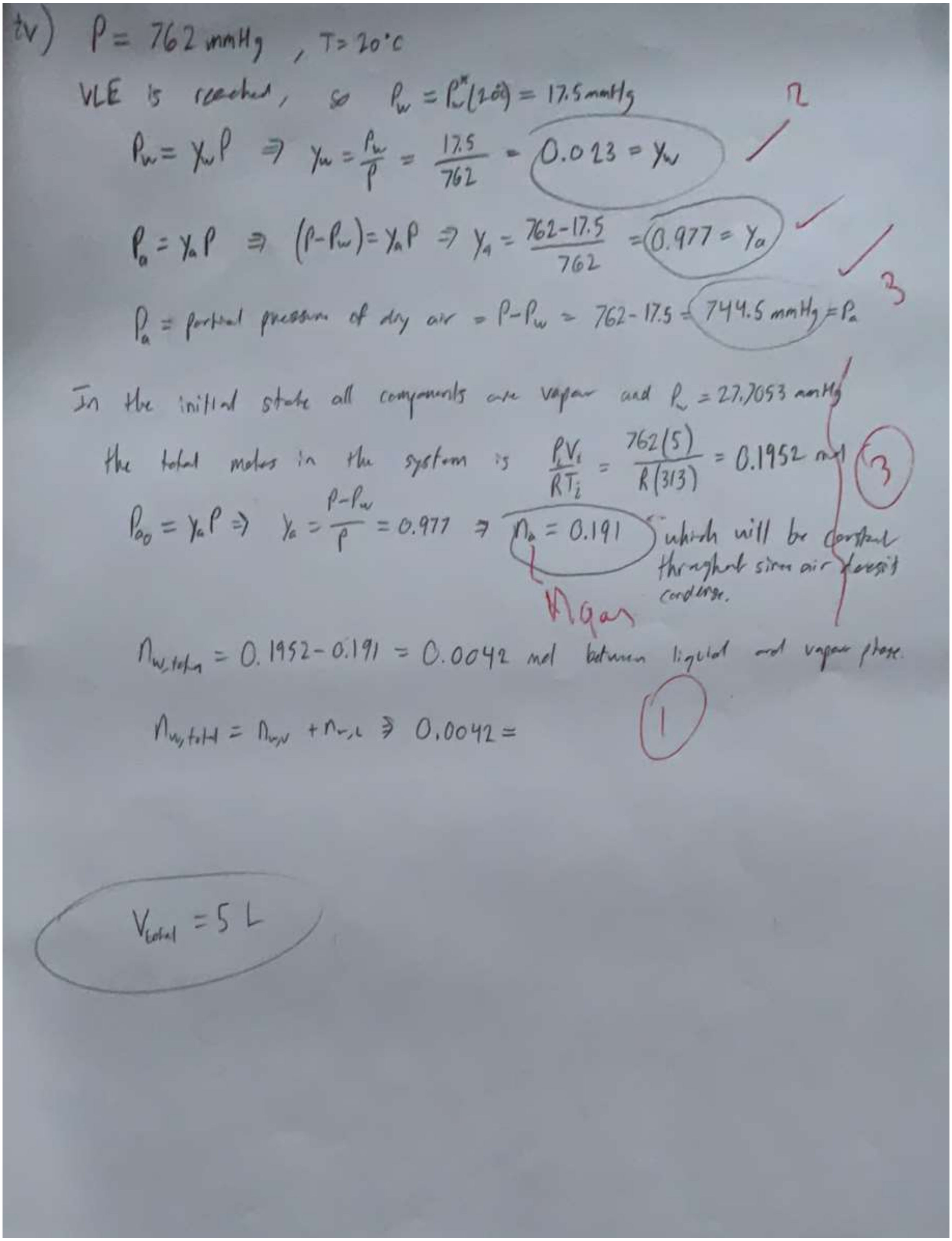
$h_{r_f} = \frac{P_w}{P_w^*(60°c)} = \frac{27.7053}{149.0} = \boxed{18.6\%}$

④

ii) $P_w^*(20°c) = 17.5\,\text{mmHg} < P_w$ ∴ there will be some condensation. There will not be enough ~~heat~~ energy to keep the water as a vapour.

④ why?

iii) $f = C - P + 2 = 2 - 3 + 2 = 1$ ∴ 1 intensive variable is required to complete the system's state. The temperature is known, and VLE has been established ∴ the state can be known completely



iv) $P = 762$ mmHg , $T = 20°C$

VLE is reached, so $P_w = P_w^*(20°) = 17.5$ mmHg 2

$$P_w = y_w P \Rightarrow y_w = \frac{P_w}{P} = \frac{17.5}{762} = \boxed{0.023 = y_w}$$ ✓

$$P_a = y_a P \Rightarrow (P - P_w) = y_a P \Rightarrow y_a = \frac{762 - 17.5}{762} = \boxed{0.977 = y_a}$$ ✓

P_a = partial pressure of dry air $= P - P_w = 762 - 17.5 = \boxed{744.5 \text{ mmHg} = P_a}$ ✓ 3

In the initial state all components are vapor and $P_w = 27.7053$ mmHg

the total moles in the system is $\frac{P_i V_i}{RT_i} = \frac{762(5)}{R(313)} = 0.1952$ mol ③

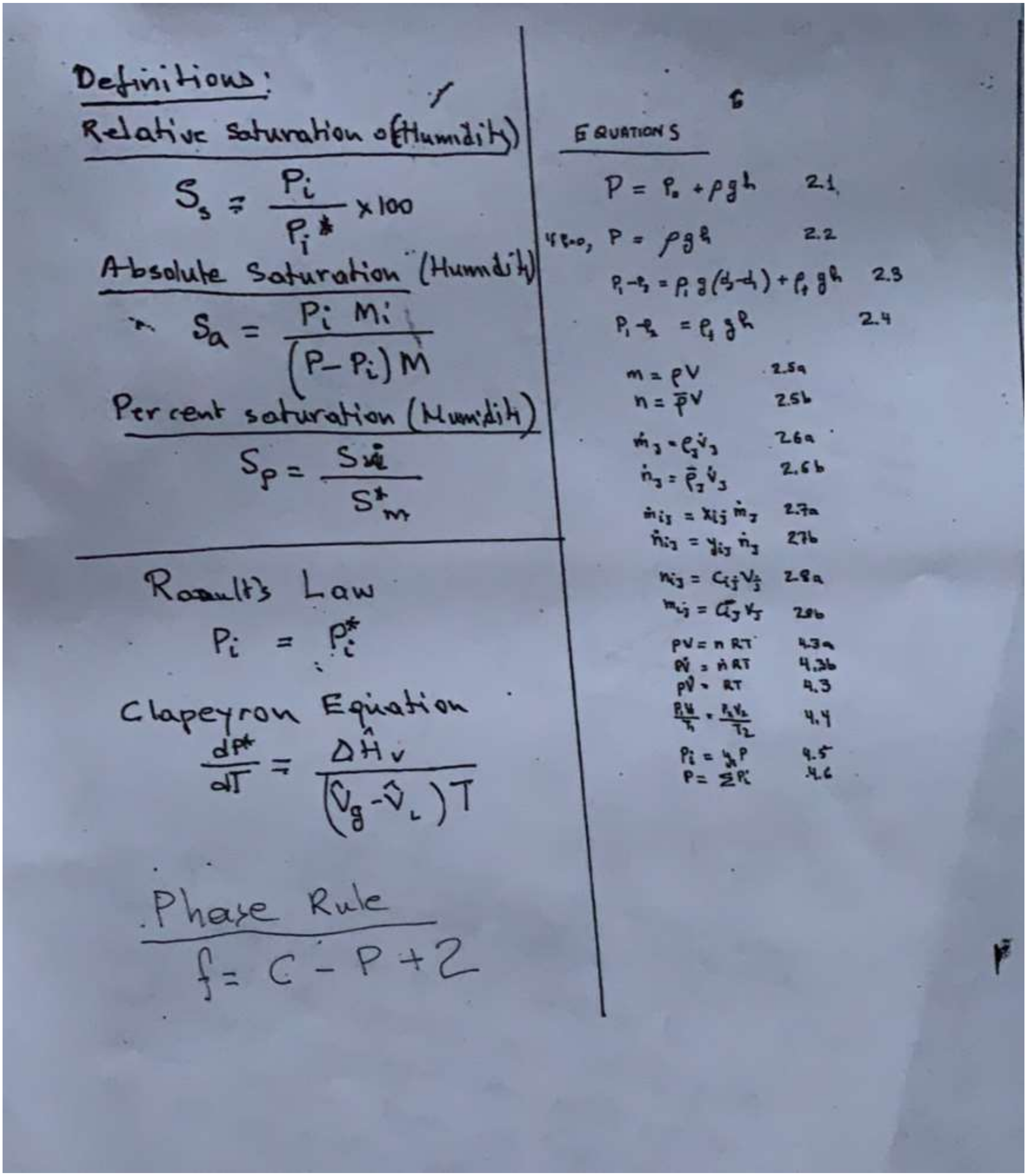
$$P_{a_0} = y_a P \Rightarrow y_a = \frac{P - P_w}{P} = 0.977 \Rightarrow \boxed{n_a = 0.191}$$ which will be constant throughout since air doesn't condense.

n_{gas}

$n_{w,total} = 0.1952 - 0.191 = 0.0042$ mol between liquid and vapor phase.

$n_{w,total} = n_{w,v} + n_{w,L} \Rightarrow 0.0042 =$ ①

$$\boxed{V_{total} = 5\text{ L}}$$



Definitions:

Relative saturation of (Humidity)

$$S_s = \frac{P_i}{P_i^*} \times 100$$

Absolute Saturation (Humidity)

$$S_a = \frac{P_i\ M_i}{(P - P_i)M}$$

Percent saturation (Humidity)

$$S_p = \frac{S_m}{S_m^*}$$

Raoult's Law

$$P_i = P_i^*$$

Clapeyron Equation

$$\frac{dP^*}{dT} = \frac{\Delta \hat{H}_v}{(\hat{V}_g - \hat{V}_L)T}$$

Phase Rule

$$f = C - P + 2$$

EQUATIONS

$$P = P_0 + \rho g h \qquad 2.1$$

If $P_0 = 0$, $P = \rho g h$ 2.2

$$P_1 - P_2 = \rho_1 g(d_2 - d_1) + \rho_f g h \qquad 2.3$$

$$P_1 - P_2 = \rho_f g h \qquad 2.4$$

$$m = \rho V \qquad 2.5a$$

$$n = \bar{\rho} V \qquad 2.5b$$

$$\dot{m}_j = \rho_j \dot{V}_j \qquad 2.6a$$

$$\dot{n}_j = \bar{\rho}_j \dot{V}_j \qquad 2.6b$$

$$\dot{m}_{ij} = x_{ij} \dot{m}_j \qquad 2.7a$$

$$\dot{n}_{ij} = y_{ij} \dot{n}_j \qquad 2.7b$$

$$n_{ij} = C_{ij} V_j \qquad 2.8a$$

$$m_{ij} = \bar{C}_{ij} V_j \qquad 2.8b$$

$$PV = nRT \qquad 4.3a$$

$$P\dot{V} = \dot{n}RT \qquad 4.3b$$

$$P\hat{V} = RT \qquad 4.3$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \qquad 4.4$$

$$P_i = y_i P \qquad 4.5$$

$$P = \sum P_i \qquad 4.6$$

2017

Test 1

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1
Class Test 1
Wednesday, October 11, 2017

5
10
6
21

NAME: Student Number

1. Answer the following questions: NO partial marks

i. For fluid flow through a bed of approximately spherical particles of diameter D, if the void fraction is ϵ and the superficial velocity is v, the **dimensionless** Reynolds number is defined as: $Re = \frac{\rho v D}{\mu(1-\epsilon)}$ where ρ is the density, and μ is the viscosity. Evaluate Re if $\rho = 0.0765\ \text{lb}_m/\text{ft}^3$, D = 10.0 mm, v = 100cm/s, $\epsilon = 0.455$ and $\mu = 1.81\times10^{-5}$ Pa·s. Make sure that your final result has no units. (3 points)

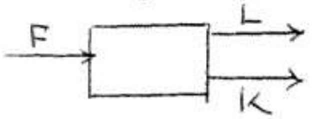
$$Re = \frac{\rho v D}{\mu(1-\epsilon)} = \frac{(.0765\frac{lbm}{ft^3})(100\frac{cm}{s})(10\ mm)}{(1.81\times10^{-5}\ Pa\cdot s)(1-0.455)}$$

$$.0765\frac{lbm}{ft^3}\cdot\frac{1000\ kg/m^3}{62.43\ lb/ft^3} = 1.23\frac{kg}{m^3} \qquad 100\frac{cm}{s}\times\frac{1\ m}{100\ cm} = 1\frac{m}{s} \qquad 10\ mm\cdot\frac{1\ m}{1000\ mm} = .01\ m$$

$$Re = \frac{(1.23\frac{kg}{m^3})(1\frac{m}{s})(.01\ m)}{(1.81\times10^{-5}\frac{N}{m^2}s)(.545)} = \frac{.0123\frac{kg}{m\,s}}{9.87\times10^{-6}\ kg\frac{m}{s^2}\cdot s} = \boxed{1250}$$

3

ii. Consider the following process. When a basis of m_F = 100 kg is used, m_L is 19 kg and m_K is 81 kg. If m_L is 500 kg what are the values of m_F and m_K? (2 points)



m_F = 100 kg
m_L = 19 kg
m_K = 81 kg

$$\frac{m_F}{m_L} = \frac{m_F}{m_L} \qquad \frac{m_K}{m_L} = \frac{m_K}{m_L}$$

2

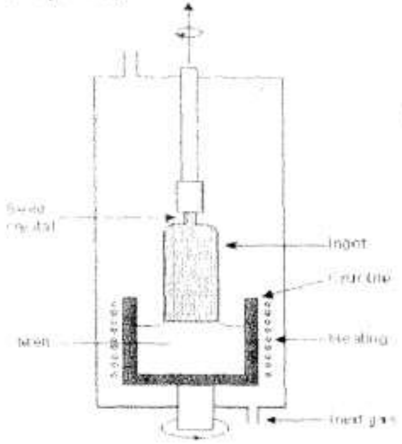
m_F = ?
m_L = 500
m_K = ?

$$\frac{100\ kg}{19\ kg} = \frac{m_F}{500\ kg} \qquad \frac{81\ kg}{19\ kg} = \frac{m_K}{500\ kg}$$

m_F = 2600 kg

m_K = 2100 kg

2. Silicon cylindrical ingots are used to manufacture silicon chips. The ingots are produced by the Czochralski process as shown in the figure below. Initially the hot liquid silicon bath (the melt) contains 100.0 kg of silicon. The cylindrical ingot has a diameter of 20.0 cm and is removed slowly from the melt (neglect the volume of the seed at the neck of the cylinder). If it takes 120 minutes to remove one half of the silicone from the bath at what rate in mm/min is the ingot removed from the melt? Assume that the density of silicon is 2.33 g/cm^3. ($V_{cylinder} = D^2h/4$) ($\pi = 3.14$) (10 points)



melt: 100 kg

d = 20cm

what rate is it removed?

takes 120 minutes to remove 1/2

$\rho_{Silicon} = 2.33 g/cm^3$

✓

$\frac{1}{2}$ removed = 50 kg × $\frac{1000g}{1kg}$ = 50 000 g

rate of volume removal = $\frac{\text{volume removed}}{\text{time}}$

$V = \pi r^2 h = \frac{\pi D^2}{4} h$

$\rho = \frac{m}{V}$

$2.33 g/cm^3 = 50\ 000 \left(\frac{\pi D^2}{4} h\right)^{-1}$

$2.33 g/cm^3 = 50\ 000 g \left(\frac{\pi (20 cm)^2}{4} h\right)^{-1}$

$2.33 g/cm^3 = \frac{159 g}{h\ cm^2}$

$h = \frac{159 g/cm^2}{2.33 g/cm^3}$

takes 120 min for h = 68.3 cm to be removed $\Longleftarrow$ h = 68.3 cm

rate of ingot removal

$= \frac{68.3 cm}{120 min} \cdot \frac{10 mm}{1 cm}$

$= \frac{683 mm}{120 min}$

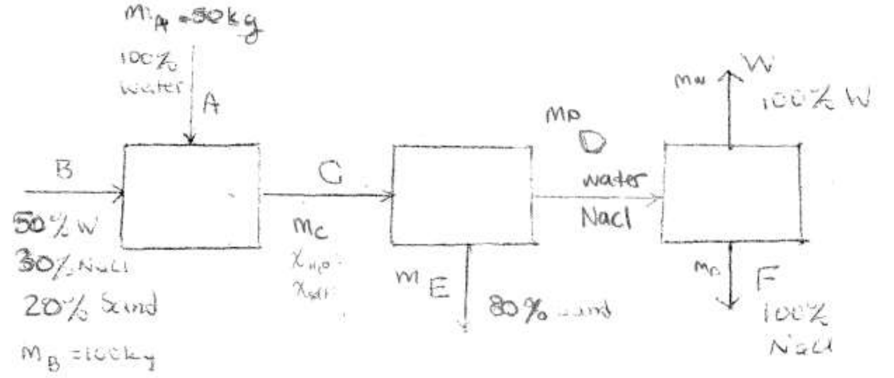
$= \boxed{5.69 mm/min}$ ✓

10

$\eta = \frac{|W|}{|Q_H|}$ $\eta = 1 - \frac{T_C}{T_H}$

3. Consider the following process shown schematically below. Stream A contains only water. The overall composition of stream B, which is a mixture of an aqueous NaCl solution and sand is shown below. Stream C enters a filter to remove the sand. The **sand free stream D** then enters an evaporator and crystallizer to obtain pure salt (F) and water(W).

i. If m_A =50 kg and m_B =100kg, find m_C, m_D, m_E, m_F, m_W and mass fraction of salt and water in steams in streams D and E (x_{SD}, x_{SE}, x_{WD}, x_{WE}) (12 points)
ii If all water is removed from stream E what is the composition of the remaining solids? (3 points)



Overall
$m_A + m_B = m_E + m_F + m_W$
$m_C = m_E + m_D$

Water
$m_A + .5 m_B = .667 m_C$
$.667 m_C = .08 m_E + .4 m_D$

sand
$.133 m_C = .8 m_E$
$.133(150 kg) = .8 m_E$
$m_E = 25$ kg ✓

m_C
50 kg water = 66.7%
50 kg water
30 kg NaCl = 20%
20 kg Sand = 13.3%
150 kg ✓

$m_C = m_E + m_D$
150 kg = 25 kg + m_D
125 kg = m_D

m_D
$.667(150) = .08(25) + .4 m_D$
$50 = .4 m_D$
$m_D = 125$ ✓
①

m_E sol'n.
$\frac{salt}{sand} = \frac{20}{13.3} = \frac{x}{20-x}$?.
$400 - 20x = 13.3x$
$400 = 33.3x$
$x = 12\%$ = salt
8% = water

m_D Where are the balances?
$\frac{20}{13.3} = \frac{x}{100-x}$
$2000 - 20x = 13.3x$
$2000 = 33.3x$
x = 60% salt
40% water
X

$.4 m_D = m_W$ $m_W = .4(125) = 50$ kg
$.6 m_D = m_F$ $m_F = .6(125) = 75$ kg

②

mass fractions
$m_C = 150$ kg
$m_D = 125$ kg
$m_E = 25$ kg
$m_F = 75$ kg
$m_W = 50$ kg
②
$x_{E salt} = \frac{3 kg}{25 kg}$ $x_{D salt} = \frac{75 kg}{125 kg} = \frac{3}{5}$
$x_{E water} = \frac{2 kg}{25 kg}$ $x_{D water} = \frac{50 kg}{125 kg} = \frac{2}{5}$

ii) 25 kg
20 kg Sand
3 kg salt
2 kg water
$\frac{20 kg}{23 kg}$ sand = 87%
$\frac{3 kg}{23 kg}$ salt = 13%

Quiz 3

⑩

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1
Quiz 3
Friday, November 10, 2017

NAME: [redacted] **Student Number** [redacted]

One mole of air, undergoes a two-step change. In the first step, it is heated at constant volume from 57°C and 3 bar to a pressure P2 and a temperature of 157°C . In the second step the pressure is changed isothermally from P_2 to 8 bar.

i. Calculate W, Q. ΔU and ΔH for both steps.

ii. Sketch the process on a Pv diagram (2 points)

$C_p = \frac{7R}{2}$ $C_v = \frac{5R}{2}$

R=8.314 J/mol K ~~=0.08134~~L bar/molK
0.08314

$T_1 = 57°C = 330K$
$P_1 = 3$ bar
$V_1 = 9.15$ L
①

$\xrightarrow{\text{constant } V}$

$T_2 = 157 = 430$ K
$P_2 = 3.91$ bar
$V_2 = 9.15$ L
②

$\xrightarrow{\text{constant } T}$

$T_3 = 430$ K
$P_3 = 8$ bar
$V_3 = 4.47$ L
③

① $PV = nRT$
$(3\text{ bar})V_1 = (1\text{mol})(.08314\,\frac{L\text{ bar}}{\text{mol K}})(330)$
$V_1 = 9.15$ L

② $PV = nRT$
$P_2(9.15) = (1\text{mol})(.08314\,\frac{L\text{ bar}}{\text{mol K}})(430K)$
$P_2 = 3.91$ bar

③ $PV = nRT$
$(8\text{ bar})V_3 = (1\text{mol})(.08314\,\frac{L\text{ bar}}{\text{mol K}})(430K)$
$V_3 = 4.47$ L

1→2 (isochoric)

constant V

$\boxed{\hat{W} = 0\text{ J/mol}}$ ✓

$Q = C_v(T_2 - T_1)$
$= \frac{5}{2}(8.314\,\frac{J}{\text{mol K}})(100K)$

$\boxed{\hat{Q} = 2078\text{ J/mol}}$ ✓

~~$\Delta U = Q + W$~~

$\boxed{\Delta\hat{U} = 2078\text{ J/mol}}$ ✓

$\Delta H = C_p(T_2 - T_1)$
$= \frac{7}{2}(8.314\,\frac{J}{\text{mol K}})(100)$

$\boxed{\Delta\hat{H} = 2910\text{ J/mol}}$ ✓

2→3 (isothermal)

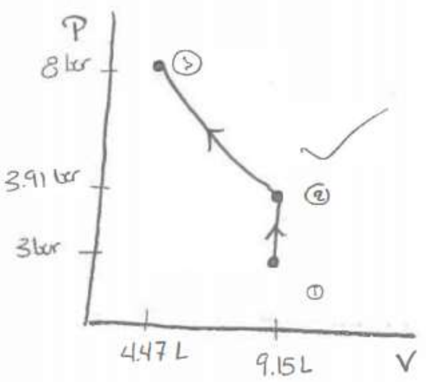
$\boxed{\begin{array}{l}\Delta\hat{U} = 0\text{ J/mol} \\ \Delta\hat{H} = 0\text{ J/mol}\end{array}}$ ✓ ✓

$W = -RT\ln\left(\frac{P_2}{P_3}\right)$
$= -(8.314\,\frac{J}{\text{mol K}})(430K)\ln\left(\frac{3.91\text{ bar}}{8\text{ bar}}\right)$

$\boxed{\hat{W} = 2559\text{ J/mol}}$

$Q = -W$ ✓

$\boxed{\hat{Q} = -2559\text{ J/mol}}$ ✓



✓

Test 2

4
14
4
22
24

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1

Class Test 2

Monday, November 20, 2017

NAME: [redacted] **Student Number** [redacted]

ATTACHED ARE (i) GENERALIZED COMPRESSIBILTY CHARTS, and (ii) A SECTION OF THE STEAM TABLES

1. Answer the following questions in the provided space:

a. An ideal gas is compressed from a high to a low pressure isothermally in a closed system. Can this process be adiabatic? TRUE FALSE You must justify your answer using the first law of thermodynamics; otherwise no credit. (2 points)

$\Delta U = Q + W$ in adiabatic, $Q = 0$

at constant temp, $\Delta U = 0$

→ so W would have to be 0 also, FALSE

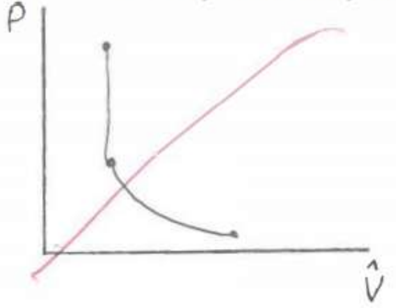
2

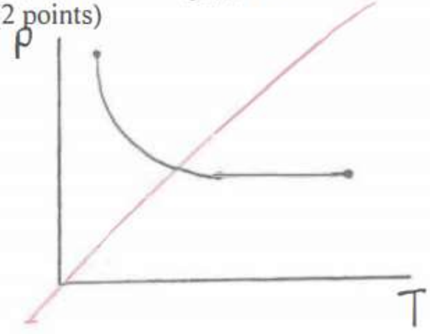
b. Superheated methanol vapour is cooled from a high temperature T1 to a lower temperature T2 at constant volume until the first drop of liquid methanol is obtained. The cooling continues until **all** methanol is liquefied. Sketch this process in a

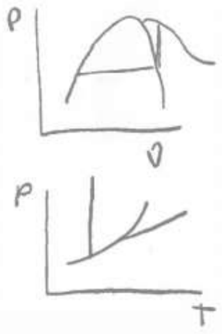
i. Pv (pressure volume) diagram ((3 points), and

ii. PT (pressure temperature) diagram (2 points)

└ constant T







c. A saturated steam – liquid mixture at 101.3kPa having a total mass of 10.0 g has a volume of 10.0 cm^3. The quality of the steam in this mixture is

(i) approximately equal to 1, or

[✓ (ii) approximately equal to zero]

Justify your choice. (2 points)

$\frac{10\,g}{18\,g/mol} = 0.556$ mol

$\hat{V} = \frac{.0001\,m^3}{0.05556}$

$= 0.0002$ => more liquid than steam (small $\hat{V}$)

2

2. A cylinder equipped with a piston contains ethylene at a pressure of 126.0 kPa and a temperature of 65.5^{O}C. The total volume of ethylene is 0.500 m^{3}.

i. What is the mass of ethylene in the cylinder? (12 points)

ii. What will be the volume if the pressure is reduced to 100.8 kPa at the same temperature of 65.5^{O}C? (3 points)

Data for Ethylene : Critical temperature: 9.0^{O}C, Critical Pressure: 50.4 kPA,

Molecular Weight of ethylene : 28 g/mol T= 282

R= 8.314 kPa m^{3}/ kmol K

$P\hat{V} = ZRT$

P = 126 kPa

V = 0.5 m^{3}

T = 338.5 K

$T_r = \frac{T}{T_c}$ $P_r = \frac{P}{P_c}$

$= \frac{338.5\ K}{282\ K}$ $= \frac{126\ kPa}{50.4\ kPa} = 2.5$

$= 1.2$

$Z = 0.55$ ✓

$P\hat{V} = ZRT$

$(126\ kPa)(0.5\ m^3) = n\,(0.55)(8.314\,\frac{kPa\ m^3}{kmol\ K})(338.5)$

$63 = 1547.8\,n$

$n = 0.04$ Kmol

$n = 40.7$ mol

12

$40.7\ mol\left(28\frac{g}{mol}\right) = \boxed{1.14\ kg}$ ✓

z changes

$P\hat{V} = zRT$

P=100.8 kPa

T= 338.5

$PV = nZRT$

$(100.8\ kPa)\,V = (0.04\ kmol)(0.\cancel{55})(8.314\,\frac{kPa\ m^3}{kmol\ k})(338.5)$

$\boxed{V = 0.614\ m^3}$

-1

②

$$\Delta H = Q + \cancel{W_s}^{\to 0}$$

$$Q = (H_2 + H_3) - H_1$$

$$Q = m_2 H_2 + m_3 H_3 - m_1 H_1$$

$$\hat{H}_1 = (\hat{H}_{ft})_v + \int_{T_{ref}}^{T_1} C_{p_v}\, dT$$

$$\hat{H}_2 = (\hat{H}_{ft})_v + \int_{T_{ref}}^{T} C_{p_v}\, dT$$

$$\hat{H}_3 = (\hat{H}_{ft})_v + \int_{T_{ref}}^{T} C_{p_v}\, dT + \Delta\hat{H}_{cond} + \int_{T_{cond}}^{T_3} C_{p_l}\, dT$$

$$= -\Delta\hat{H}_{vap} + \int_{383}^{323} C_{p_l}\, dT$$

$$\dot{Q} = -\Delta H_{vap} + C_p(50-110)$$

$$\Delta H_{cond} = -33.47 \text{ kJ/mol}$$

$$Q = -460.8 \text{ kJ/s}$$

$$\Delta H_v = 2693.4 - 467.13$$

$$= 2226 \text{ kJ/kg}$$

$$Q = 2226.3$$

$$\hat{H}_1 = (\hat{H}_{i1})_v + \cancel{\int_{T_{ref}}^{T_1} C_{p_v}\,dT}^{\,0} = 0$$

$$\hat{H}_2 = H_{T_1} + \int_{T_m}^{T_1} C_{p_v}\,dT =$$

$$H_3 = H_{T_1} + \Delta H_{cond} + \int_{T_{rf}}^{T_3} C_{p_L}\,dT$$

~~$\Delta H = (m_2 H_2 + H_3)$~~

$$\Delta H = \cancel{m_2}\overset{0}{\hat{H}_2} + m_3\hat{H}_3 - \cancel{\hat{m}_1\hat{H}_1}^{\,0} = Q + \cancel{W_s}^{\,0}$$

$$Q = \Delta H_{cond.} + \int_{110}^{10} C_{p_L}\,dT$$

3. A stream of toluene vapour at its boiling point (110^{0} C) and 1 atm and flowing at a rate of 3000.0 g/s enters a unit. Part of entering stream is evaporated and another part is cooled as shown below.

i. What is the total heat requirement for this process? (12 points)

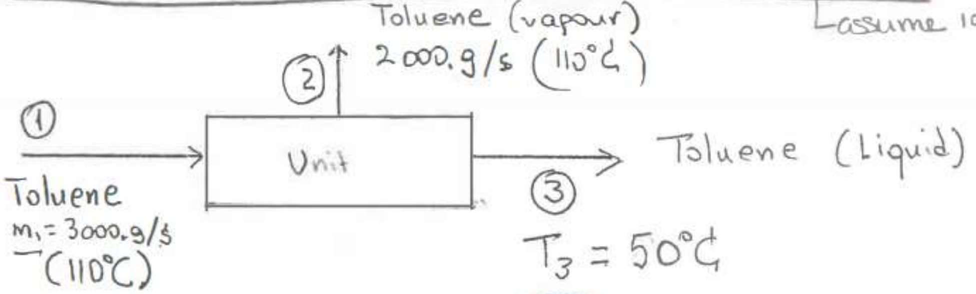
ii. If saturated steam at 150kPa is available to supply the heat calculated in part i, how many kg of steam are required per second? Assume complete condensation of the steam. (3 points)

Use the following data:

Molecular weight of toluene: 92.13 g/mol. ΔH_{vap} 33.47 kJ/mol at the boiling point.

Assume that the heat capacity of toluene is constant and equal to 150.0×10^{-3} kJ/mol K

assume ideal gas?



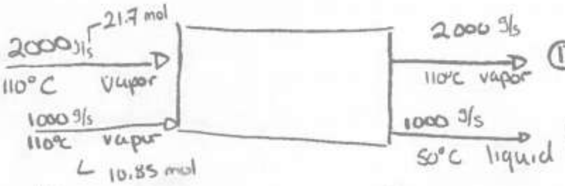
2

m_1 = 3000 g/s　　n_1 = 32.56 mol/s

m_2 = 2000 g/s　　n_2 = 21.7 mol/s

m_3 = 1000 g/s　　n_3 = 10.86 mol/s

assume bubble point – all liquid except for 1st bubble



① = ΔH_{vap} = 33.47 kJ/mol s

② = 9 kJ/mol s

1

② $$\Delta H = \left((H_f)_{tref} + \int_{tref}^{110} C_p\, dT - \cancel{(\Delta H)_{tref}} + \cancel{\int_{tref}^{50} C_p\, dT} \right)$$

tref = 50°C

$$\Delta H = -\int_{323}^{383} .150\, dT$$

$$= -.150(383-323)$$

$$= -9 \frac{KJ}{mol}$$

Where is the energy balance?

$$\cancel{Q = \dot{m}_1 \Delta H_1 + \dot{m}_2 \Delta H_2}$$

$$\cancel{= (21.7 \tfrac{mol}{s})(33.47 \tfrac{kJ}{mol}) - (10.85 \tfrac{mol}{s})(9 \tfrac{kJ}{mol})}$$

$$\cancel{= 726.3 \tfrac{KJ}{s} - 97.65 \tfrac{kJ}{s}}$$

$$\cancel{= \boxed{628.7 \tfrac{KJ}{s}}}$$

Sat Steam 150 kPa: vap $\Delta H = 2693.4 \frac{KJ}{kg}$

liquid $\Delta H = 467.124 \frac{KJ}{kg}$

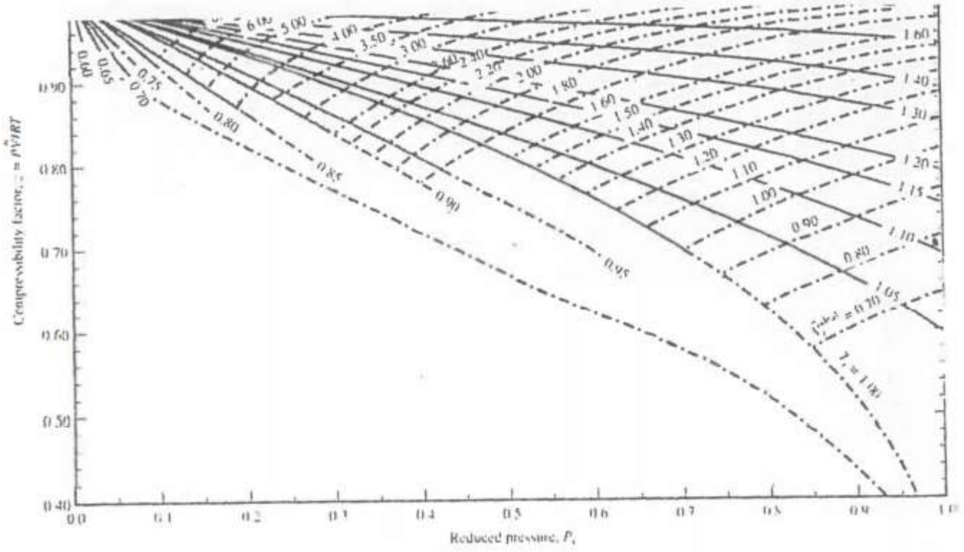
$\dot{m}(2693.4) = 628.7$ kJ

$\dot{m} = .233 \frac{kg}{s}$

$\dot{m}(2693.4 + 467.126) = 628.7$ kJ

1 +2 $\dot{m} = .199 \frac{kg}{s}$

low pressures. (Based on Footnote 7.)



$$P_r = \frac{P}{P_c} \quad ; \quad T_r = \frac{T}{T_c} \quad ,$$

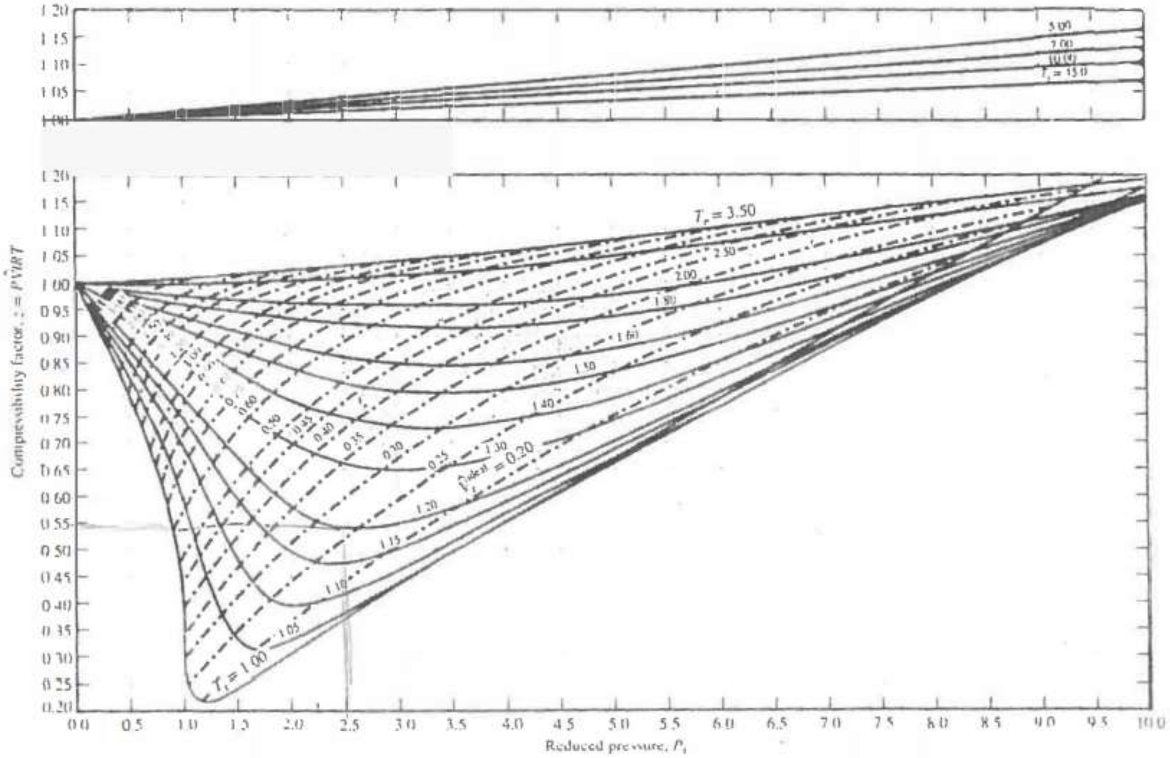


FIGURE 5.4-3 Generalized compressibility chart, medium pressures. (Based on Footnote 7.)

S

specific volume (cm³/g)
Specific internal energy (kJ/kg)
specific enthalpy (kJ/kg)

Table F.2: Superheated Steam, SI Units

P/kPa (t^{sat}/°C)		sat liq	sat vap	TEMPERATURE: t °C (TEMPERATURE, T kelvins)							
				75 (348.15)	100 (373.15)	125 (398.15)	150 (423.15)	175 (448.15)	200 (473.15)	225 (498.15)	250 (523.15)
1 (6.98)	V	1.000	129200.	160640.	172180.	183720.	195270.	206810.	218350.	229890.	241430.
	U	29.334	2385.2	2480.8	2516.4	2552.3	2588.5	2624.9	2561.7	2698.8	2736.3
	H	29.335	2514.4	2641.5	2688.6	2736.0	2783.7	2831.7	2880.1	2928.7	2977.7
	S	0.1060	8.9767	9.3828	9.5136	9.6365	9.7527	9.8629	9.9679	10.0681	10.1641
10 (45.83)	V	1.010	14670.	16030.	17190.	18350.	19510.	20660.	21820.	22980.	24130.
	U	191.822	2438.0	2479.7	2515.6	2551.6	2588.0	2624.5	2681.4	2698.6	2736.1
	H	191.832	2584.8	2640.0	2687.5	2735.2	2783.1	2831.2	2879.6	2928.4	2977.4
	S	0.6493	8.1511	8.3168	8.4486	8.5722	8.6888	8.7994	8.9045	9.0049	9.1010
20 (60.09)	V	1.017	7649.8	8000.0	8584.7	9167.1	9748.0	10320.	10900.	11480.	12060.
	U	251.432	2456.9	2478.4	2514.6	2550.9	2587.4	2624.1	2661.0	2698.3	2735.8
	H	251.453	2609.9	2638.4	2686.3	2734.2	2782.3	2830.6	2879.2	2928.0	2977.1
	S	0.8321	7.9094	7.9933	8.1261	8.2504	8.3676	8.4785	8.5839	8.6844	8.7806
30 (69.12)	V	1.022	5229.3	5322.0	5714.4	6104.6	6493.2	6880.8	7267.5	7653.8	8039.7
	U	289.271	2468.6	2477.1	2513.6	2550.2	2586.8	2623.6	2660.7	2698.0	2735.6
	H	289.302	2625.4	2636.8	2685.1	2733.3	2781.6	2830.0	2878.7	2927.6	2976.8
	S	0.9441	7.7695	7.8024	7.9363	8.0614	8.1791	8.2903	8.3960	8.4967	8.5930
40 (75.89)	V	1.027	3993.4	....	4279.2	4573.3	4865.8	5157.2	5447.8	5738.0	6027.7
	U	317.609	2477.1	....	2512.6	2549.4	2586.2	2623.2	2660.3	2697.7	2735.4
	H	317.650	2636.9	....	2683.8	2732.3	2780.9	2829.5	2878.2	2927.2	2976.5
	S	1.0261	7.6709	....	7.8009	7.9268	8.0450	8.1566	8.2624	8.3633	8.4598
50 (81.35)	V	1.030	3240.2	....	3418.1	3654.5	3889.3	4123.0	4356.0	4588.5	4820.5
	U	340.513	2484.0	....	2511.7	2548.6	2585.6	2622.7	2659.9	2697.4	2735.1
	H	340.564	2646.0	....	2682.6	2731.4	2780.1	2828.9	2877.7	2926.8	2976.1
	S	1.0912	7.5947	....	7.6953	7.8219	7.9406	8.0526	8.1587	8.2598	8.3564
75 (91.79)	V	1.037	2216.9	....	2269.8	2429.4	2587.3	2744.2	2900.2	3055.8	3210.9
	U	384.374	2496.7	....	2509.2	2546.7	2584.2	2621.6	2659.0	2696.7	2734.5
	H	384.451	2663.0	....	2679.4	2720.9	2778.2	2827.4	2876.6	2925.8	2975.3
	S	1.2131	7.4570	....	7.5014	7.6300	7.7500	7.8629	7.9697	8.0712	8.1681
100 (99.63)	V	1.043	1693.7	....	1695.5	1816.7	1936.3	2054.7	2172.3	2289.4	2406.1
	U	417.406	2506.1	....	2506.6	2544.8	2582.7	2620.4	2658.1	2695.9	2733.9
	H	417.511	2675.4	....	2676.2	2726.5	2776.3	2825.9	2875.4	2924.9	2974.5
	S	1.3027	7.3598	....	7.3618	7.4923	7.6137	7.7275	7.8349	7.9369	8.0342
101.325 (100.00)	V	1.044	1673.0	....	1673.0	1792.7	1910.7	2027.7	2143.8	2259.3	2374.5
	U	418.959	2506.5	....	2506.5	2544.7	2582.6	2620.4	2658.1	2695.9	2733.9
	H	419.064	2676.0	....	2676.0	2726.4	2776.2	2825.8	2875.3	2924.8	2974.5
	S	1.3069	7.3554	....	7.3554	7.4860	7.6075	7.7213	7.8288	7.9308	8.0280
125 (105.99)	V	1.049	1374.6	....	....	1449.1	1545.6	1641.0	1735.6	1829.6	1923.2
	U	444.224	2513.4	....	....	2542.9	2581.2	2619.3	2657.2	2695.2	2733.3
	H	444.356	2685.2	....	....	2724.0	2774.4	2824.4	2874.2	2923.9	2973.7
	S	1.3740	7.2847	....	....	7.3844	7.5072	7.6219	7.7300	7.8324	7.9300
150 (111.37)	V	1.053	1159.0	....	....	1204.0	1285.2	1365.2	1444.4	1523.0	1601.3
	U	466.968	2519.5	....	....	2540.9	2579.7	2618.1	2656.3	2694.4	2732.7
	H	467.126	2693.4	....	....	2721.5	2772.5	2822.9	2872.9	2922.9	2972.9
	S	1.4336	7.2234	....	....	7.2953	7.4194	7.5352	7.6439	7.7468	7.8447
175 (116.06)	V	1.057	1003.34	....	....	1028.8	1099.1	1168.2	1236.4	1304.1	1371.3
	U	486.815	2524.7	....	....	2538.9	2578.2	2616.9	2655.3	2693.7	2732.1
	H	487.000	2700.3	....	....	2719.0	2770.5	2821.3	2871.7	2921.9	2972.0
	S	1.4849	7.1716	....	....	7.2191	7.3447	7.4614	7.5708	7.6741	7.7724
200 (120.23)	V	1.061	885.44	....	....	897.47	959.54	1020.4	1080.4	1139.8	1198.9
	U	504.489	2529.2	....	....	2536.9	2576.6	2615.7	2654.4	2692.9	2731.4
	H	504.701	2706.3	....	....	2716.4	2768.5	2819.8	2870.5	2920.9	2971.2
	S	1.5301	7.1268	....	....	7.1523	7.2794	7.3971	7.5072	7.6110	7.7096
225 (123.99)	V	1.064	792.97	....	....	795.25	850.97	905.44	959.06	1012.1	1064.7
	U	520.465	2533.2	....	....	2534.8	2575.1	2614.5	2653.5	2692.2	2730.8
	H	520.705	2711.6	....	....	2713.8	2766.5	2818.2	2869.3	2919.9	2970.4
	S	1.5705	7.0873	....	....	7.0928	7.2213	7.3400	7.4508	7.5551	7.6540
250 (127.43)	V	1.068	718.44	....	....	....	764.09	813.47	861.98	909.91	957.41
	U	535.077	2536.8	....	....	....	2573.5	2613.3	2652.5	2691.4	2730.2
	H	535.343	2716.4	....	....	....	2764.5	2816.7	2868.0	2918.9	2969.6
	S	1.6071	7.0520	....	....	....	7.1689	7.2886	7.4001	7.5050	7.6042
275 (130.60)	V	1.071	657.04	....	....	....	693.00	738.21	782.55	826.29	869.61
	U	548.564	2540.0	....	....	....	2571.9	2612.1	2651.6	2690.7	2729.6
	H	548.858	2720.7	....	....	....	2762.5	2815.1	2866.8	2917.9	2968.7
	S	1.6407	7.0201	....	....	....	7.1211	7.2419	7.3541	7.4594	7.5590
300 (133.54)	V	1.073	605.56	....	....	....	633.74	675.49	716.35	756.60	796.44
	U	561.107	2543.0	....	....	....	2570.3	2610.8	2650.6	2689.9	2729.0
	H	561.429	2724.7	....	....	....	2760.4	2813.5	2865.5	2916.9	2967.9
	S	1.6716	6.9909	....	....	....	7.0771	7.1990	7.3119	7.4177	7.5176

SUMMARY OF EQUATIONS.
(CLOSED SYSTEM)

First Law: (Closed system)

$$d\hat{U} = d\hat{Q} + d\hat{W}$$

$$\Delta\hat{U} = \hat{Q} + \hat{W}$$

Open system $\Delta\hat{H} = \hat{Q} + \hat{W}_s$

Definitions: $(\hat{H}, C_{p}, C_{v})$

Enthalpy $H = \hat{U} + P\hat{V}$

Heat capacity:

(Any substance) $C_v = \left(\frac{d\hat{U}}{dT}\right)_V$ and $C_p = \left(\frac{d\hat{H}}{dT}\right)_P$

- For a reversible expansion/compression. per mol of gas (ideal or non-ideal)

$$d\hat{W} = -P\,d\hat{V}$$

- Adiabatic Process $\Rightarrow d\bar{Q} = 0$

Work and heat for different processes (Ideal gas)

(i) Constant Volume

$$\hat{W} = 0$$

$$\hat{Q} = \int_{T_1}^{T_2} C_v\,dT$$

(ii) Constant Pressure

$$d\hat{W} = -P\,d\hat{V}$$

$$\hat{W} = -P(\hat{V}_2 - \hat{V}_1)$$

$$\hat{Q} = \Delta\hat{H}$$

$$Q = \int_{T_1}^{T_2} C_p\,dT$$

(iii) Constant Temperature (Remember ideal gas)

$$d\hat{U} = 0$$

$$d\hat{Q} = -d\hat{W} \Rightarrow dQ = \overset{\text{Why?}}{+}\int_{V_1}^{V_2} P\,d\hat{V}$$

$$Q = -W \quad \begin{cases} \hat{W} = -RT \ln \dfrac{\hat{V}_2}{\hat{V}_1} \\ \hat{W} = -RT \ln \dfrac{P_1}{P_2} \end{cases}$$

(iv) Reversible adiabatic process

$$\text{Path} \rightarrow \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}, \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}, \quad P_1V_1^{\gamma} = P_2V_2^{\gamma} = C.$$

$$Q = 0$$

$$W = C_v\,(T_2 - T_1)$$

$$\hat{W} = \frac{P_2\hat{V}_2 - P_1\hat{V}_1}{\gamma - 1}$$

(v) Polytropic process.

Similar to adiabatic (replace γ with δ)

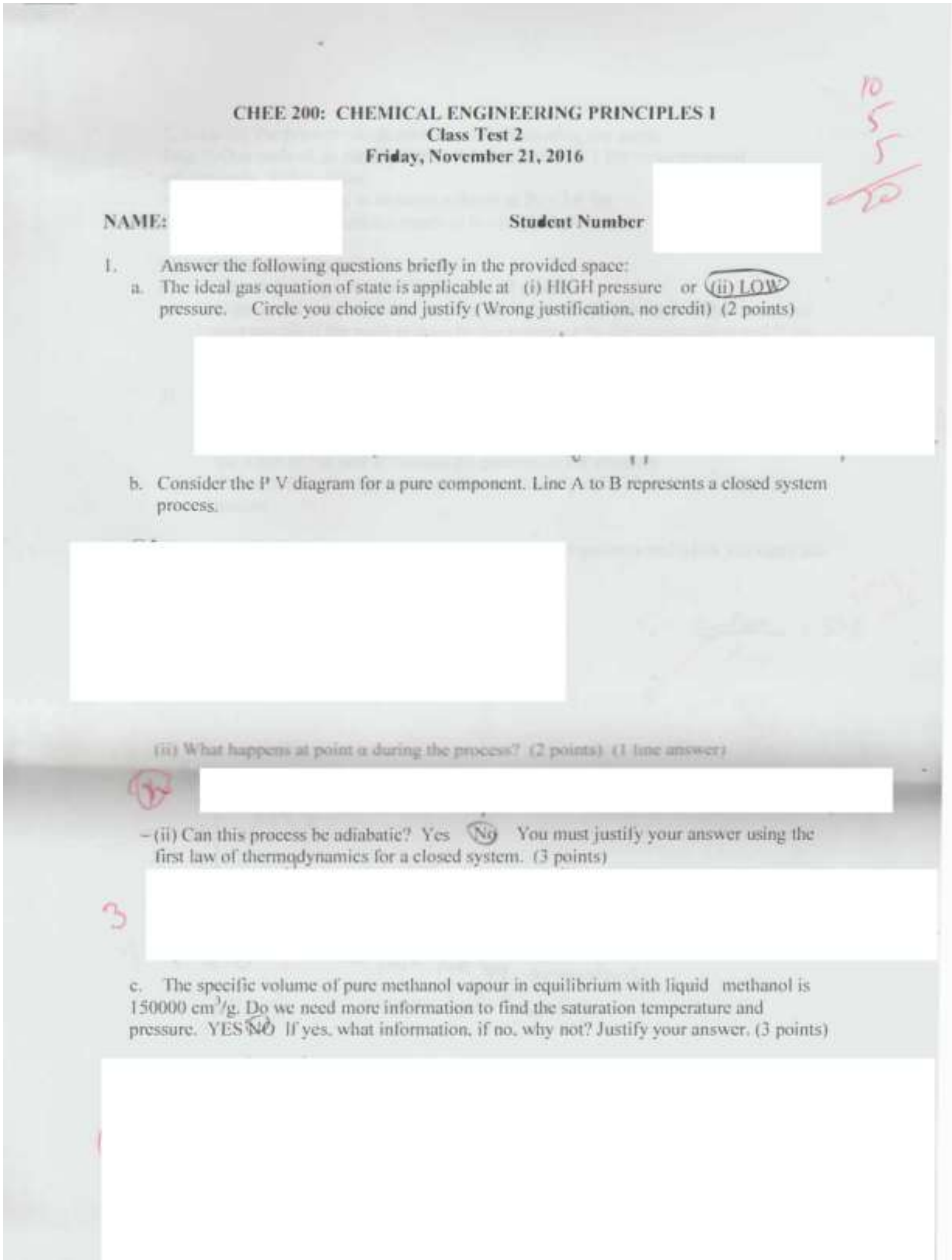
$$P_1V_1^{\delta} = P_2V_2^{\delta} = \text{const}$$

$$W = C_v\,(T_2 - T_1)$$

$$W = \frac{P_2\hat{V}_2 - P_1\hat{V}_1}{\delta - 1}$$

2016

Test 2



10
5
5
/20

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES I
Class Test 2
Friday, November 21, 2016

NAME: [redacted] **Student Number** [redacted]

1. Answer the following questions briefly in the provided space:
   a. The ideal gas equation of state is applicable at (i) HIGH pressure or [✓ (ii) LOW] pressure. Circle you choice and justify (Wrong justification, no credit) (2 points)

[redacted]

   b. Consider the P V diagram for a pure component. Line A to B represents a closed system process.

[redacted]

(ii) What happens at point α during the process? (2 points) (1 line answer)

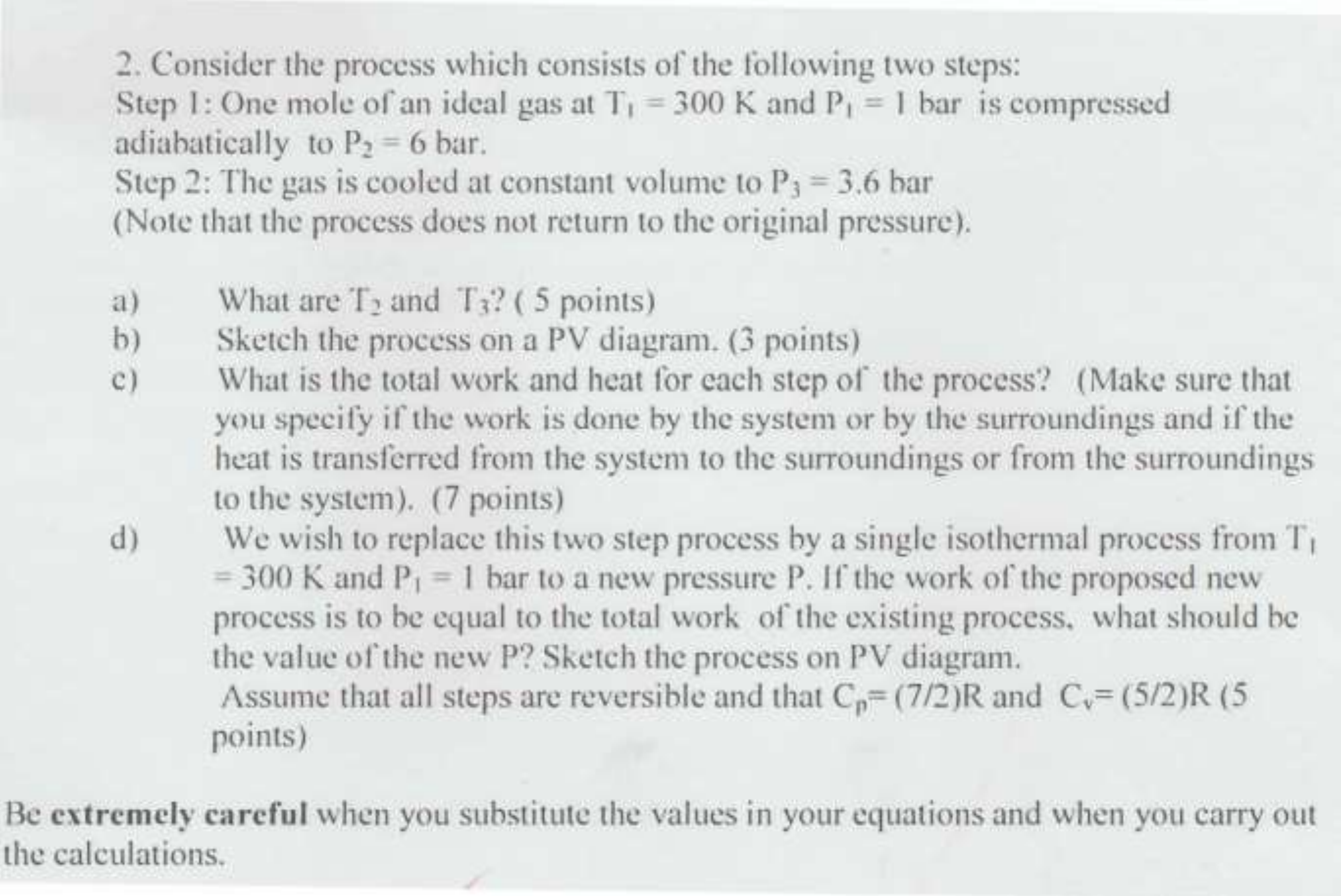
2 [redacted]

-(ii) Can this process be adiabatic? Yes [✓ No] You must justify your answer using the first law of thermqdynamics for a closed system. (3 points)

3 [redacted]

   c. The specific volume of pure methanol vapour in equilibrium with liquid methanol is 150000 cm^3/g. Do we need more information to find the saturation temperature and pressure. YES [✓ NO] If yes, what information, if no, why not? Justify your answer. (3 points)

[redacted]



2. Consider the process which consists of the following two steps:
Step 1: One mole of an ideal gas at $T_1 = 300$ K and $P_1 = 1$ bar is compressed adiabatically to $P_2 = 6$ bar.
Step 2: The gas is cooled at constant volume to $P_3 = 3.6$ bar
(Note that the process does not return to the original pressure).

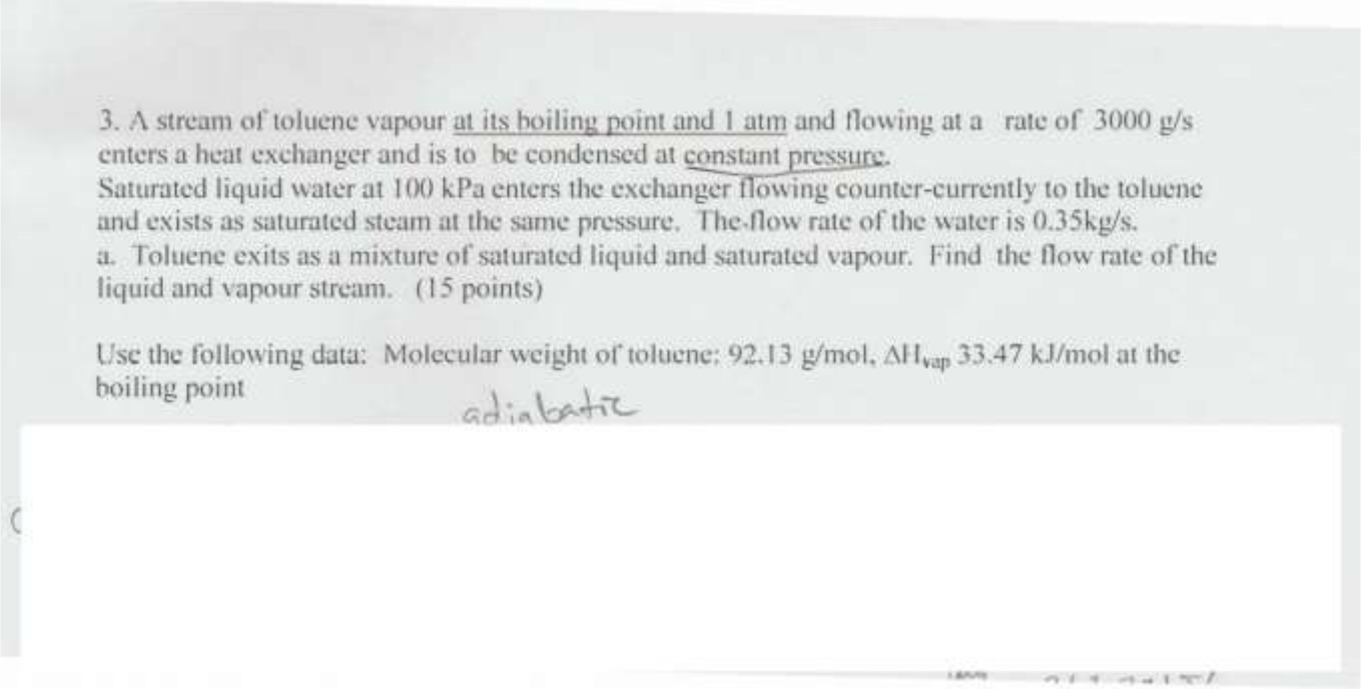
a) What are T_2 and T_3? (5 points)

b) Sketch the process on a PV diagram. (3 points)

c) What is the total work and heat for each step of the process? (Make sure that you specify if the work is done by the system or by the surroundings and if the heat is transferred from the system to the surroundings or from the surroundings to the system). (7 points)

d) We wish to replace this two step process by a single isothermal process from $T_1 = 300$ K and $P_1 = 1$ bar to a new pressure P. If the work of the proposed new process is to be equal to the total work of the existing process, what should be the value of the new P? Sketch the process on PV diagram.
Assume that all steps are reversible and that $C_p = (7/2)R$ and $C_v = (5/2)R$ (5 points)

Be **extremely careful** when you substitute the values in your equations and when you carry out the calculations.



3. A stream of toluene vapour at its boiling point and 1 atm and flowing at a rate of 3000 g/s enters a heat exchanger and is to be condensed at constant pressure.
Saturated liquid water at 100 kPa enters the exchanger flowing counter-currently to the toluene and exists as saturated steam at the same pressure. The flow rate of the water is 0.35kg/s.
a. Toluene exits as a mixture of saturated liquid and saturated vapour. Find the flow rate of the liquid and vapour stream. (15 points)

Use the following data: Molecular weight of toluene: 92.13 g/mol, ΔH_{vap} 33.47 kJ/mol at the boiling point

adiabatic

2015

Test 1a

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1
Class Test 1
Friday, October 2, 2015

NAME:

Student Number

1. The equation describing the variation of the rate constant k with temperature (T) is given by
 $k = Ae^{-E/RT}$, $y = ae^{-b/x}$
 where k is the rate constant (sec^{-1}), and T is temperature in K. An experiment showed that when T= 333.0 K, the rate constant k= 7.391 min^{-1}, when the temperature is 370.0 K, the rate constant is 54.64 min^{-1}.

a. Determine the constants A and E by linearizing the equation above. (Numerical values and units required) (15 points)
 $R = 8.314 \frac{J}{mol\ K}$.

b. Using the equation above, we determined the rate constants k_{315K} and k_{350K} at the two different temperatures of T= 315 K and 400 K (Do not calculate these values).
 Do you agree with this following statement *in italics*?
 Both k_{315K} and k_{400K} are equally accurate because we linearized the equation.
 If you do not agree with this statement, state **why**. Which one of the two constants is expected to be more accurate? Justify your choice. (5 points)

2. Consider a tank containing a liquid whose density is known. The gauge pressure (P_g) at the bottom of the tank is known. What other information and data do you need to estimate the mass of the liquid in the tank? You must define all variables and write the necessary equations that you will use to determine the mass of the liquid. (10 points)

3. The mixture consists of 13.08[illegible]% (mass) zinc, 62.97 %(mass) nickel and the rest being titanium particles. The mass of the mixture is 50 kg.
   We wish to reduce the nickel content of the mixture from 62.97 % to 40.0% by removing nickel particles from the mixture. No zinc or titanium is to be removed from or added to the mixture.
   a. What is the final mass of the mixture after the removal of the nickel particles? (15 points)
   b. What is the mole fraction of zinc and titanium in the mixture? (5 points)
   (Atomic weights: Zn: 65.4 g/gmol, Ti : 47.9 g/gmol, Ni : 58.7 g/gmol)
   (ρ_{Zn} = 7.13 g/cm^3 , ρ_{ti} = 4.50 g/cm^3 ρ_{Ni} = 8.91 g/cm^3)

EQUATIONS

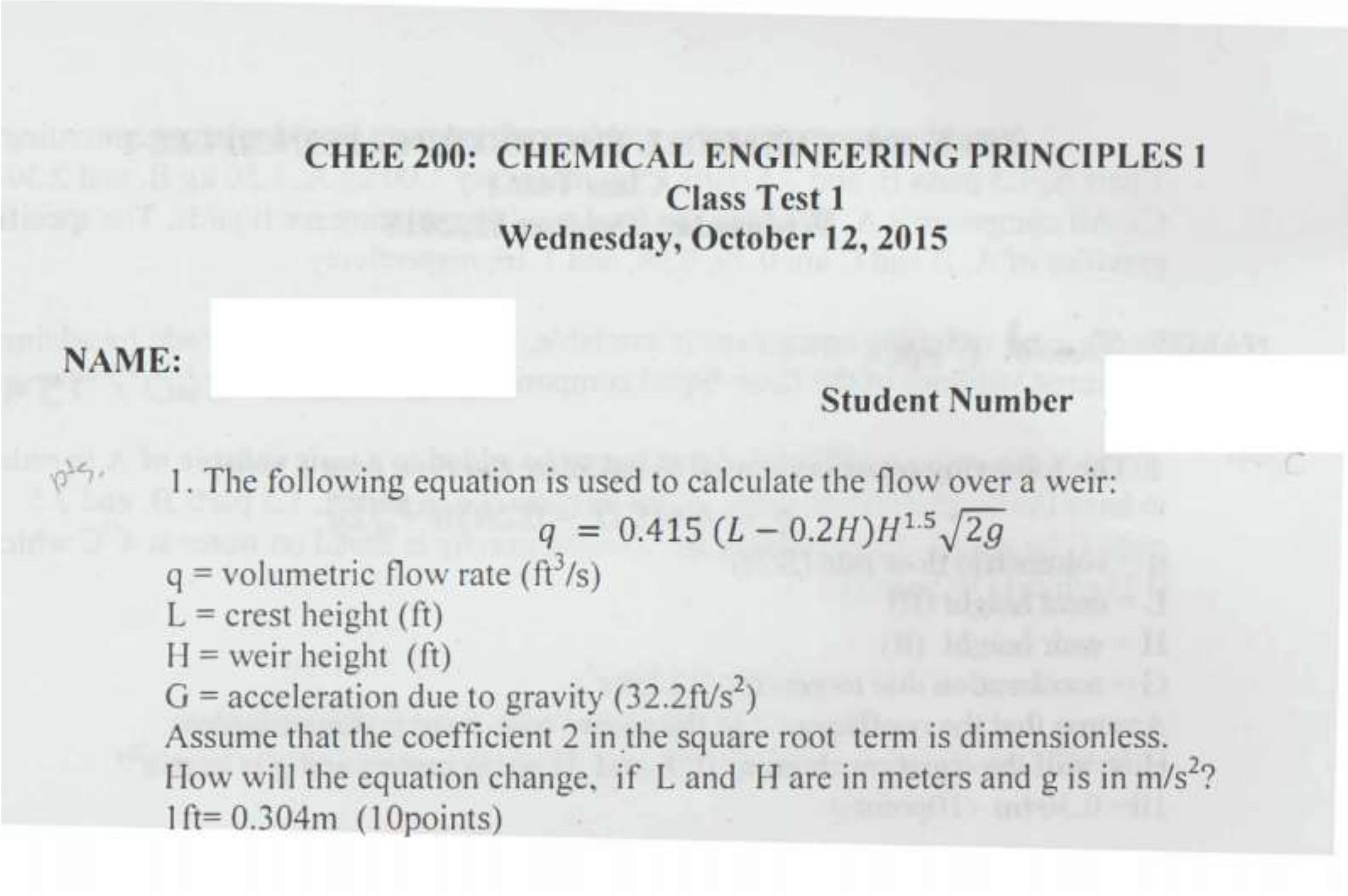
$$P = P_0 + \rho g h \qquad 2.1$$

$$\text{if } P_0=0, \quad P = \rho g h \qquad 2.2$$

$$P_1 - P_2 = \rho_1 g (d_2 - d_1) + \rho_f g h \qquad 2.3$$

$$P_1 - P_2 = \rho_f g h \qquad 2.4$$

Test 1b



CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1

Class Test 1

Wednesday, October 12, 2015

NAME: [redacted]

Student Number [redacted]

pts. 1. The following equation is used to calculate the flow over a weir:

$$q = 0.415\,(L - 0.2H)H^{1.5}\sqrt{2g}$$

q = volumetric flow rate (ft^3/s)
L = crest height (ft)
H = weir height (ft)
G = acceleration due to gravity ($32.2 ft/s^2$)

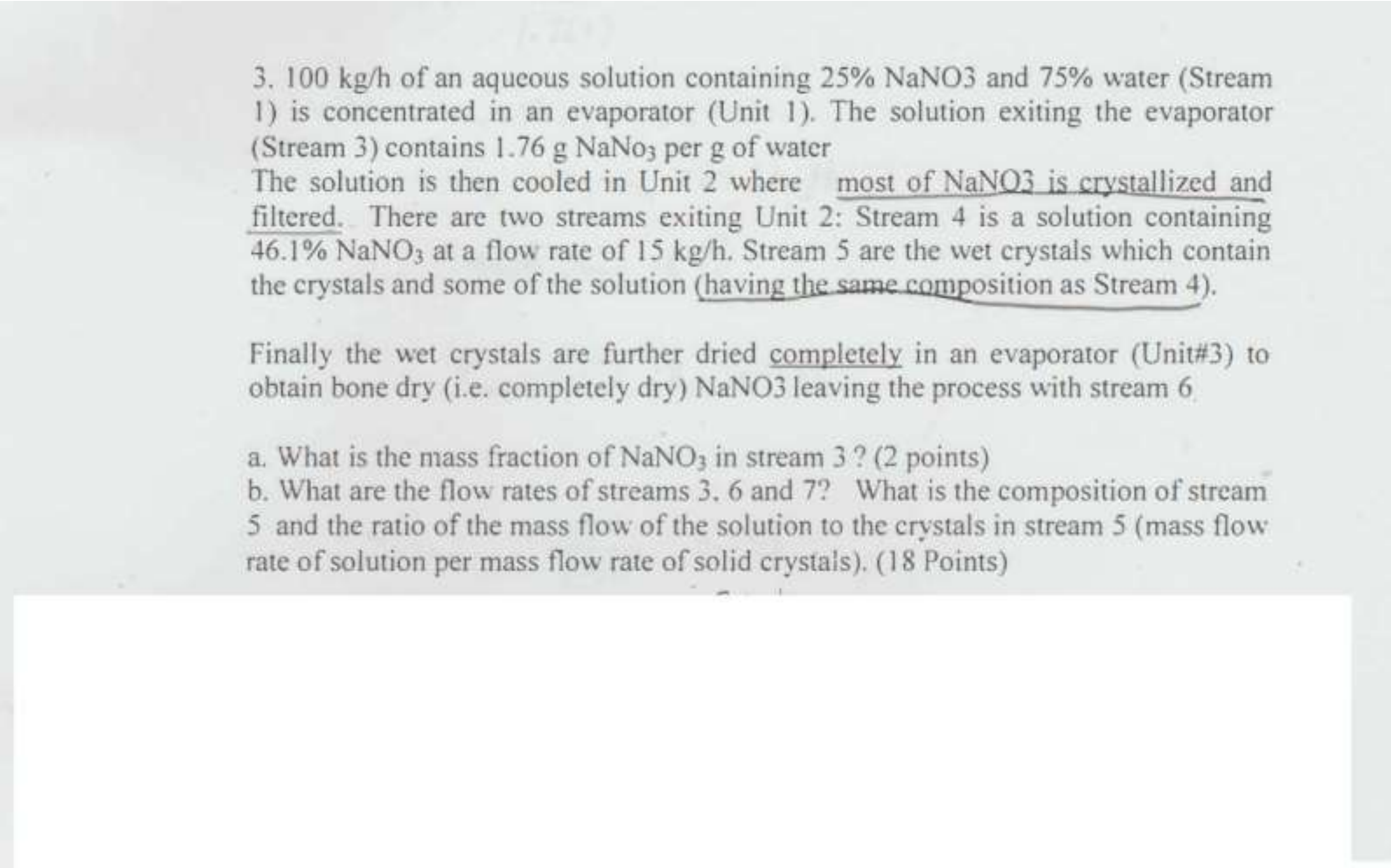
Assume that the coefficient 2 in the square root term is dimensionless.
How will the equation change, if L and H are in meters and g is in m/s^2?
1ft= 0.304m (10points)

2

2. You have been given the problem of making a liquid mixture consisting of 1 part A, 1.5 parts B, and 2.5 parts C by mass (say 1.00 kg A, 1.50 kg B, and 2.50 kg C). All components A, B, C and the final resulting mixture are liquids. The specific gravities of A, B and C are 0.79, 0.98, and 1.16, respectively.

Because no weighing equipment is available, the mixture must be made by adding measured volumes of the three liquid components.

What is the volume of B and C that has to be added to a **unit volume of A** in order to have the correct composition of the mixture (i.e. 1 part A, 1.5 parts B, and 2.5 parts C by mass). (Assume that the specific gravity is based on water at $4^{O}C$ which is 1kg/liter) (10 points)



3. 100 kg/h of an aqueous solution containing 25% NaNO3 and 75% water (Stream 1) is concentrated in an evaporator (Unit 1). The solution exiting the evaporator (Stream 3) contains 1.76 g $NaNo_3$ per g of water
The solution is then cooled in Unit 2 where most of NaNO3 is crystallized and filtered. There are two streams exiting Unit 2: Stream 4 is a solution containing 46.1% $NaNO_3$ at a flow rate of 15 kg/h. Stream 5 are the wet crystals which contain the crystals and some of the solution (having the same composition as Stream 4).

Finally the wet crystals are further dried completely in an evaporator (Unit#3) to obtain bone dry (i.e. completely dry) NaNO3 leaving the process with stream 6

a. What is the mass fraction of $NaNO_3$ in stream 3 ? (2 points)
b. What are the flow rates of streams 3, 6 and 7? What is the composition of stream 5 and the ratio of the mass flow of the solution to the crystals in stream 5 (mass flow rate of solution per mass flow rate of solid crystals). (18 Points)

Test 2

CHEE 200: CHEMICAL ENGINEERING PRINCIPLES 1
Class Test 2
Friday, October 30, 2015

NAME: **Student Number**

I. Water enters a tank having a volume of 90 liters. Initially the volume of the water in the tank is 10 liters. The flow rate of the water into the tank is 10 Liters/minute and the flow rate out of the tank is 6 Liters/minute.

a) Is this a batch, semi-batch or continuous process? Is it transient or steady state? Justify your answer with not more than three sentences) (4 points)
b) How long will it take for the tank to fill? The density of water may be assumed to be 1kg/liters (6 points)

2. A gas stream (#1) containing benzene (20.0%), toluene (60.0%) and nitrogen (20%) is mixed with a stream (#2) of pure nitrogen. The stream leaving the mixer (#3) contains 50.0% nitrogen. The flow rate of stream #1 is 100.0 mol/hour (i.e. $\dot{n}_1$ = 100mol/h)

100,0 mol/h

By doing a degree of freedom analysis, determine if you have enough information to calculate the flow rate of stream 2 ($\dot{n}_2$) and the mole fractions of benzene (y_{B3}) and toluene (y_{T3}) in stream 3. How many degrees of freedom do you have ? Answer one of the three following alternatives:

- If you have enough information, calculate the values $\dot{n}_2$, y_{B3}, and y_{T3}
- If you do not have sufficient information, state what other information you need and write <u>but do not solve the equations.</u>
- If you have more information than you need, determine if are the data consisten

(20)

3. A gaseous stream (#1) containing 25.0% carbon dioxide and 75.0% ammonia is to be scrubbed to reduce its ammonia content. The temperature of stream (#1) is 137.0^{O}C and the pressure is 2.00 atm. Under these temperature and pressure conditions the volumetric flow rate of the entering stream is 1680 liters/minute. (Assume ideal gas behavior)

The molar flow rate of ammonia leaving with the acid stream (n_{A4})is 60 mol/min.

i. What is the partial pressure of ammonia in stream 3 if the temperature of the stream is 77^{O}C and the volumetric flow rate is 920 Liters/minute? What is the volumetric flow rate of stream #3 (in Liters/minute) at STP (15 points)
ii. What is the concentration of ammonia (mol/liter) at the conditions of Stream 3? (5 points)

R=0.08202 (liters atm)/(mol K)

EQUATIONS

$$P = P_0 + \rho g h \qquad 2.1$$

if $P_0 = 0$, $$P = \rho g h \qquad 2.2$$

$$P_1 - P_2 = \rho_1 g (d_2 - d_1) + \rho_f g h \qquad 2.3$$

$$P_1 - P_2 = \rho_f g h \qquad 2.4$$

$$m = \rho V \qquad 2.5a$$

$$n = \bar{\rho} V \qquad 2.5b$$

$$\dot{m}_J = \rho_J \dot{V}_J \qquad 2.6a$$

$$\dot{n}_J = \bar{\rho}_J \dot{V}_J \qquad 2.6b$$

$$\dot{m}_{iJ} = x_{iJ} \dot{m}_J \qquad 2.7a$$

$$\dot{n}_{iJ} = y_{iJ} \dot{n}_J \qquad 2.7b$$

$$n_{iJ} = \underline{C_{iJ}} V_J \qquad 2.8a$$

$$m_{iJ} = C^{m}_{iJ} V_J \qquad 2.8b$$

$$PV = nRT \qquad 4.3a$$

$$P\dot{V} = \dot{n} RT \qquad 4.3b$$

$$P\hat{V} = RT \qquad 4.3$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \qquad 4.4$$

$$P_i = y_i P \qquad 4.5$$

$$P = \sum P_i \qquad 4.6$$

Test 3

CHEE 200 CHEMICAL ENGINEERING PRINCIPLES

Class test III

November 27 2015

ATTACHED ARE THE GENERALIZED COMPRESSIBILITY CHARTS AND A SECTION OF THE STEAM TABLES

1 What is the temperature in a rigid cylinder containing 0.61 kg of ethylene?
The pressure in the vessel is 115kPa and the gas volume is $0.25 m^3$.
Data for ethylene: Critical Temperature: 9.0 °C, Critical Pressure : 50.40 kPa
Molecular weight : 28
$R=8.314\ m^3\ kPa/\ kmol\ K$
(10 points)

2. A cylinder equipped with a piston contains 2 moles of an ideal gas. The gas is compressed from an initial pressure of 1 bar and an initial volume of 24 Liters to a final pressure of 15 bar and a final volume of 2 Liters by a two-step process: adiabatic compression followed by cooling at constant volume.

i. Calculate the Q,W, ΔU and ΔH for this process (15 points))

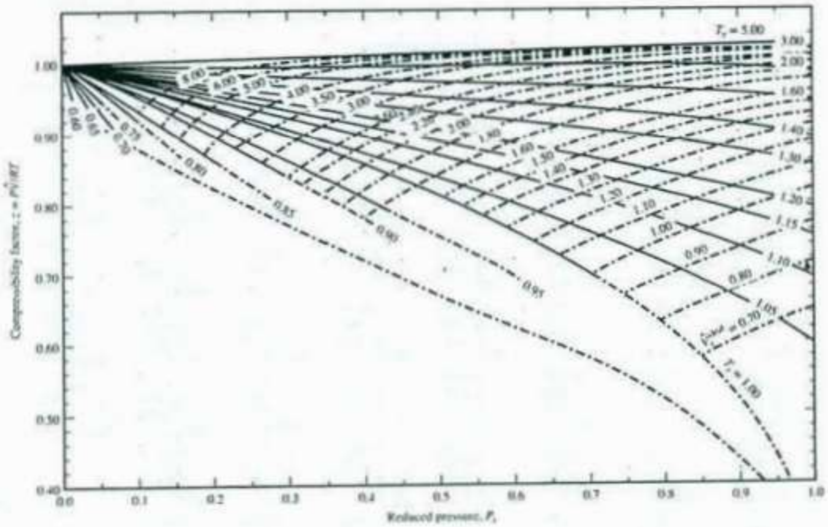
ii. Sketch the path in a PV (pressure-volume) diagram (2points)

iii. Sketch the path in a PT (pressure Temperature) diagram (3 points)

R= 0.08314 L bar/mol K

3. **Four grams** of saturated liquid water $100^{\circ}C$ are heated in a cylinder equipped a piston using the following steps. First the water is heated until it all evaporates and the heating is continued at constant pressure until a total volume of 15,000 cm^3 is reached. The heating continues further at constant temperature until the pressure is 275 kPa. What is the final volume, the **total** heat supplied, and the **total** work (make sure you specify if the work is done by the system or by the surroundings) for this process. (20 points)

FIGURE 5.4-2 Generalized compressibility chart, low pressures. (Based on Footnote 7.)



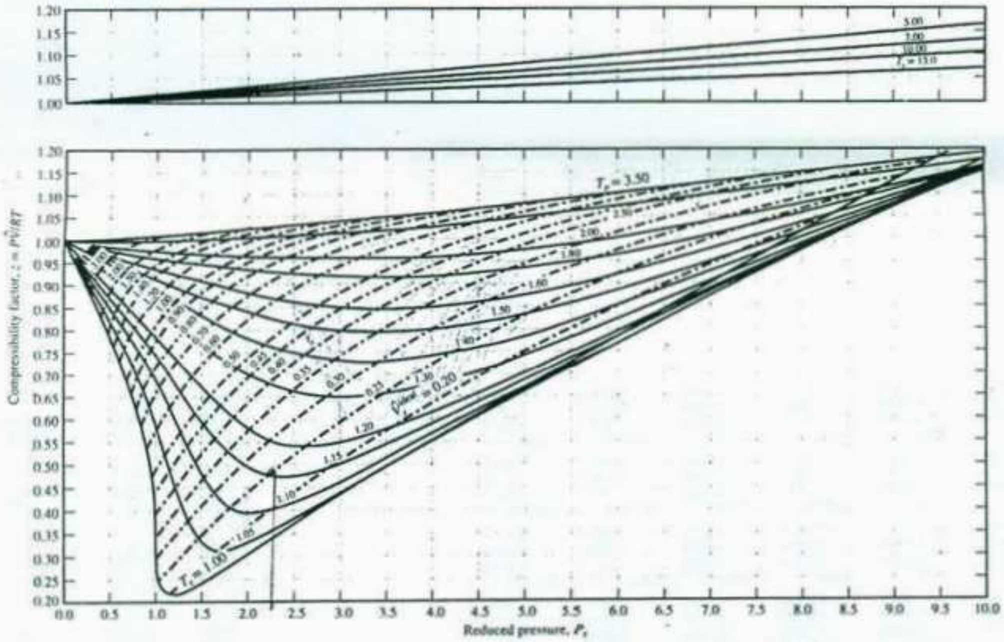


FIGURE 5.4-3 Generalized compressibility chart, medium pressures. (Based on Footnote 7.)

S

B

specific volume (cm³/g)
Specific internal energy (kJ/kg)
specific enthalpy (kJ/kg)

Table F.2: Superheated Steam, SI Units

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 75 (348.15)	100 (373.15)	125 (398.15)	150 (423.15)	175 (448.15)	200 (473.15)	225 (498.15)	250 (523.15)
1 (6.98)	V	1.000	129200.	160640.	172180.	183720.	195270.	206810.	218350.	229890.	241430.
	U	29.334	2385.2	2480.8	2516.4	2552.3	2588.5	2624.9	2661.7	2698.8	2736.3
	H	29.335	2514.4	2641.5	2688.6	2736.0	2783.7	2831.7	2880.1	2928.7	2977.7
	S	0.1060	8.9767	9.3828	9.5136	9.6365	9.7527	9.8629	9.9679	10.0681	10.1641
10 (45.83)	V	1.010	14670.	16030.	17190.	18350.	19510.	20660.	21820.	22980.	24130.
	U	191.822	2438.0	2479.7	2515.6	2551.6	2588.0	2624.5	2661.4	2698.6	2736.1
	H	191.832	2584.8	2640.0	2687.5	2735.2	2783.1	2831.2	2879.6	2928.4	2977.4
	S	0.6493	8.1511	8.3168	8.4486	8.5722	8.6888	8.7994	8.9045	9.0049	9.1010
20 (60.09)	V	1.017	7649.8	8000.0	8584.7	9167.1	9748.0	10320.	10900.	11480.	12060.
	U	251.432	2456.9	2478.4	2514.6	2550.9	2587.4	2624.1	2661.0	2698.3	2735.8
	H	251.453	2609.9	2638.4	2686.3	2734.2	2782.3	2830.6	2879.2	2928.0	2977.1
	S	0.8321	7.9094	7.9933	8.1261	8.2504	8.3676	8.4785	8.5839	8.6844	8.7806
30 (69.12)	V	1.022	5229.3	5322.0	5714.4	6104.6	6493.2	6880.8	7267.5	7653.8	8039.7
	U	289.271	2468.6	2477.1	2513.6	2550.2	2586.8	2623.6	2660.7	2698.0	2735.6
	H	289.302	2625.4	2636.8	2685.1	2733.3	2781.6	2830.0	2878.7	2927.6	2976.8
	S	0.9441	7.7695	7.8024	7.9363	8.0614	8.1791	8.2903	8.3960	8.4967	8.5930
40 (75.89)	V	1.027	3993.4	....	4279.2	4573.3	4865.8	5157.2	5447.8	5738.0	6027.7
	U	317.609	2477.1	....	2512.6	2549.4	2586.2	2623.2	2660.3	2697.7	2735.4
	H	317.650	2636.9	....	2683.8	2732.3	2780.9	2829.5	2878.2	2927.2	2976.5
	S	1.0261	7.6709	....	7.8009	7.9268	8.0450	8.1566	8.2624	8.3633	8.4598
50 (81.35)	V	1.030	3240.2	....	3418.1	3654.5	3889.3	4123.0	4356.0	4588.5	4820.5
	U	340.513	2484.0	....	2511.7	2548.6	2585.6	2622.7	2659.9	2697.4	2735.1
	H	340.564	2646.0	....	2682.6	2731.4	2780.1	2828.9	2877.7	2926.8	2976.1
	S	1.0912	7.5947	....	7.6953	7.8219	7.9406	8.0526	8.1587	8.2598	8.3564
75 (91.79)	V	1.037	2216.9	....	2269.8	2429.4	2587.3	2744.2	2900.2	3055.8	3210.9
	U	384.374	2496.7	....	2509.2	2546.7	2584.2	2621.6	2659.0	2696.7	2734.5
	H	384.451	2663.0	....	2679.4	2728.9	2778.2	2827.4	2876.6	2925.8	2975.3
	S	1.2131	7.4570	....	7.5014	7.6300	7.7500	7.8629	7.9697	8.0712	8.1681
100 (99.63)	V	1.043	1693.7	....	1695.5	1816.7	1936.3	2054.7	2172.3	2289.4	2406.1
	U	417.406	2506.1	....	2506.6	2544.8	2582.7	2620.4	2658.1	2695.9	2733.9
	H	417.511	2675.4	....	2676.2	2726.5	2776.3	2825.9	2875.4	2924.9	2974.5
	S	1.3027	7.3598	....	7.3618	7.4923	7.6137	7.7275	7.8349	7.9369	8.0342
101.325 (100.00)	V	1.044	1673.0	....	1673.0	1792.7	1910.7	2027.7	2143.8	2259.3	2374.5
	U	418.959	2506.5	....	2506.5	2544.7	2582.6	2620.4	2658.1	2695.9	2733.9
	H	419.064	2676.0	....	2676.0	2726.4	2776.2	2825.8	2875.3	2924.8	2974.5
	S	1.3069	7.3554	....	7.3554	7.4860	7.6075	7.7213	7.8288	7.9308	8.0280
125 (105.99)	V	1.049	1374.6	....	....	1449.1	1545.6	1641.0	1735.6	1829.6	1923.2
	U	444.224	2513.4	....	....	2542.9	2581.2	2619.3	2657.2	2695.2	2733.3
	H	444.356	2685.2	....	....	2724.0	2774.4	2824.4	2874.2	2923.9	2973.7
	S	1.3740	7.2847	....	....	7.3844	7.5072	7.6219	7.7300	7.8324	7.9300
150 (111.37)	V	1.053	1159.0	....	....	1204.0	1285.2	1365.2	1444.4	1523.0	1601.3
	U	466.968	2519.5	....	....	2540.9	2579.7	2618.1	2656.3	2694.4	2732.7
	H	467.126	2693.4	....	....	2721.5	2772.5	2822.9	2872.9	2922.9	2972.9
	S	1.4336	7.2234	....	....	7.2953	7.4194	7.5352	7.6439	7.7468	7.8447
175 (116.06)	V	1.057	1003.34	....	....	1028.8	1099.1	1168.2	1236.4	1304.1	1371.3
	U	486.815	2524.7	....	....	2538.9	2578.2	2616.9	2655.3	2693.7	2732.1
	H	487.000	2700.3	....	....	2719.0	2770.5	2821.3	2871.7	2921.9	2972.0
	S	1.4849	7.1716	....	....	7.2191	7.3447	7.4614	7.5708	7.6741	7.7724
200 (120.23)	V	1.061	885.44	....	....	897.47	959.54	1020.4	1080.4	1139.8	1198.9
	U	504.489	2529.2	....	....	2536.9	2576.6	2615.7	2654.4	2692.9	2731.4
	H	504.701	2706.3	....	....	2716.4	2768.5	2819.8	2870.5	2920.9	2971.2
	S	1.5301	7.1268	....	....	7.1523	7.2794	7.3971	7.5072	7.6110	7.7096
225 (123.99)	V	1.064	792.97	....	....	795.25	850.97	905.44	959.06	1012.1	1064.7
	U	520.465	2533.2	....	....	2534.8	2575.1	2614.5	2653.5	2692.2	2730.8
	H	520.705	2711.6	....	....	2713.8	2766.5	2818.2	2869.3	2919.9	2970.4
	S	1.5705	7.0873	....	....	7.0928	7.2213	7.3400	7.4508	7.5551	7.6540
250 (127.43)	V	1.068	718.44	....	....	....	764.09	813.47	861.98	909.91	957.41
	U	535.077	2536.8	....	....	....	2573.5	2613.3	2652.5	2691.4	2730.2
	H	535.343	2716.4	....	....	....	2764.5	2816.7	2868.0	2918.9	2969.6
	S	1.6071	7.0520	....	....	....	7.1689	7.2886	7.4001	7.5050	7.6042
275 (130.60)	V	1.071	657.04	....	....	....	693.00	738.21	782.55	826.29	869.61
	U	548.564	2540.0	....	....	....	2571.9	2612.1	2651.6	2690.7	2729.6
	H	548.858	2720.7	....	....	....	2762.5	2815.1	2866.8	2917.9	2968.7
	S	1.6407	7.0201	....	....	....	7.1211	7.2419	7.3541	7.4594	7.5590
300 (133.54)	V	1.073	605.56	....	....	....	633.74	675.49	716.35	756.60	796.44
	U	561.107	2543.0	....	....	....	2570.3	2610.8	2650.6	2689.9	2729.0
	H	561.429	2724.7	....	....	....	2760.4	2813.5	2865.5	2916.9	2967.9
	S	1.6716	6.9909	....	....	....	7.0771	7.1990	7.3119	7.4177	7.5176

Table F.2. Superheated Steam, SI Units (Continued)

				TEMPERATURE: t °C (TEMPERATURE: T kelvins)							
P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	300 (573.15)	350 (623.15)	400 (673.15)	450 (723.15)	500 (773.15)	550 (823.15)	600 (873.15)	650 (923.15)
1 (6.98)	V	1.000	129200.	264500.	287580.	310660.	333730.	356810.	379880.	402960.	426040.
	U	29.334	2385.2	2812.3	2889.9	2969.1	3049.9	3132.4	3216.7	3302.6	3390.3
	H	29.335	2514.4	3076.8	3177.5	3279.7	3383.6	3489.2	3596.5	3705.6	3816.4
	S	0.1060	8.9767	10.3450	10.5133	10.6711	10.8200	10.9612	11.0957	11.2243	11.3476
10 (45.83)	V	1.010	14670.	26440.	28750.	31060.	33370.	35670.	37980.	40290.	42600.
	U	191.822	2438.0	2812.2	2889.8	2969.0	3049.8	3132.3	3216.6	3302.6	3390.3
	H	191.832	2584.8	3076.6	3177.3	3279.6	3383.5	3489.1	3596.5	3705.5	3816.3
	S	0.6493	8.1511	9.2820	9.4504	9.6083	9.7572	9.8984	10.0329	10.1616	10.2849
20 (60.09)	V	1.017	7649.8	13210.	14370.	15520.	16680.	17830.	18990.	20140.	21300.
	U	251.432	2456.9	2812.0	2889.6	2968.9	3049.7	3132.3	3216.5	3302.5	3390.2
	H	251.453	2609.9	3076.4	3177.1	3279.4	3383.4	3489.0	3596.4	3705.4	3816.2
	S	0.8321	7.9094	8.9618	9.1303	9.2882	9.4372	9.5784	9.7130	9.8416	9.9650
30 (69.12)	V	1.022	5229.3	8810.8	9581.2	10350.	11120.	11890.	12660.	13430.	14190.
	U	289.271	2468.6	2811.8	2889.5	2968.7	3049.6	3132.2	3216.5	3302.5	3390.2
	H	289.302	2625.4	3076.1	3176.9	3279.3	3383.3	3488.9	3596.3	3705.4	3816.2
	S	0.9441	7.7695	8.7744	8.9430	9.1010	9.2499	9.3912	9.5257	9.6544	9.7778
40 (75.89)	V	1.027	3993.4	6606.5	7184.6	7762.5	8340.1	8917.6	9494.9	10070.	10640.
	U	317.609	2477.1	2811.6	2889.4	2968.6	3049.5	3132.1	3216.4	3302.4	3390.1
	H	317.650	2636.9	3075.9	3176.8	3279.1	3383.1	3488.8	3596.2	3705.3	3816.1
	S	1.0261	7.6709	8.6413	8.8100	8.9680	9.1170	9.2583	9.3929	9.5216	9.6450
50 (81.35)	V	1.030	3240.2	5283.9	5746.7	6209.1	6671.4	7133.5	7595.5	8057.4	8519.2
	U	340.513	2484.0	2811.5	2889.2	2968.5	3049.4	3132.0	3216.3	3302.3	3390.1
	H	340.564	2646.0	3075.7	3176.6	3279.0	3383.0	3488.7	3596.1	3705.2	3816.0
	S	1.0912	7.5947	8.5380	8.7068	8.8649	9.0139	9.1552	9.2898	9.4185	9.5419
75 (91.79)	V	1.037	2216.9	3520.5	3829.4	4138.0	4446.4	4754.7	5062.8	5370.9	5678.9
	U	384.374	2496.7	2811.0	2888.9	2968.2	3049.2	3131.8	3216.1	3302.2	3389.9
	H	384.451	2663.0	3075.1	3176.1	3278.6	3382.7	3488.4	3595.8	3705.0	3815.9
	S	1.2131	7.4570	8.3502	8.5191	8.6773	8.8265	8.9678	9.1025	9.2312	9.3546
100 (99.63)	V	1.043	1693.7	2638.7	2870.8	3102.5	3334.0	3565.3	3796.5	4027.7	4258.8
	U	417.406	2506.1	2810.6	2888.6	2968.0	3049.0	3131.6	3216.0	3302.0	3389.8
	H	417.511	2675.4	3074.5	3175.6	3278.2	3382.4	3488.1	3595.6	3704.8	3815.7
	S	1.3027	7.3598	8.2166	8.3858	8.5442	8.6934	8.8348	8.9695	9.0982	9.2217
101.325 (100.00)	V	1.044	1673.0	2604.2	2833.2	3061.9	3290.3	3518.7	3746.9	3975.0	4203.1
	U	418.959	2506.5	2810.6	2888.5	2968.0	3048.9	3131.6	3215.9	3302.0	3389.8
	H	419.064	2676.0	3074.4	3175.6	3278.2	3382.3	3488.1	3595.6	3704.8	3815.7
	S	1.3069	7.3554	8.2105	8.3797	8.5381	8.6873	8.8287	8.9634	9.0922	9.2156
125 (105.99)	V	1.049	1374.6	2109.7	2295.6	2481.2	2666.5	2851.7	3036.8	3221.8	3406.7
	U	444.224	2513.4	2810.2	2888.2	2967.7	3048.7	3131.4	3215.8	3301.9	3389.7
	H	444.356	2685.2	3073.9	3175.2	3277.8	3382.0	3487.9	3595.4	3704.6	3815.5
	S	1.3740	7.2847	8.1129	8.2823	8.4408	8.5901	8.7316	8.8663	8.9951	9.1186
150 (111.37)	V	1.053	1159.0	1757.0	1912.2	2066.9	2221.5	2375.9	2530.2	2684.5	2838.6
	U	466.968	2519.5	2809.7	2887.9	2967.4	3048.5	3131.2	3215.6	3301.7	3389.5
	H	467.126	2693.4	3073.3	3174.7	3277.5	3381.7	3487.6	3595.1	3704.4	3815.3
	S	1.4336	7.2234	8.0280	8.1976	8.3562	8.5056	8.6472	8.7819	8.9108	9.0343
175 (116.06)	V	1.057	1003.34	1505.1	1638.3	1771.1	1903.7	2036.1	2168.4	2300.7	2432.9
	U	486.815	2524.7	2809.3	2887.5	2967.1	3048.3	3131.0	3215.4	3301.6	3389.4
	H	487.000	2700.3	3072.7	3174.2	3277.1	3381.4	3487.3	3594.9	3704.2	3815.1
	S	1.4849	7.1716	7.9561	8.1259	8.2847	8.4341	8.5758	8.7106	8.8394	8.9630
200 (120.23)	V	1.061	885.44	1316.2	1432.8	1549.2	1665.3	1781.2	1897.1	2012.9	2128.6
	U	504.489	2529.2	2808.8	2887.2	2966.9	3048.0	3130.8	3215.3	3301.4	3389.2
	H	504.701	2706.3	3072.1	3173.8	3276.7	3381.1	3487.0	3594.7	3704.0	3815.0
	S	1.5301	7.1268	7.8937	8.0638	8.2226	8.3722	8.5139	8.6487	8.7776	8.9012
225 (123.99)	V	1.064	792.97	1169.2	1273.1	1376.6	1479.9	1583.0	1686.0	1789.0	1891.9
	U	520.465	2533.2	2808.4	2886.9	2966.6	3047.8	3130.6	3215.1	3301.2	3389.1
	H	520.705	2711.6	3071.5	3173.3	3276.3	3380.8	3486.8	3594.4	3703.8	3814.8
	S	1.5705	7.0873	7.8385	8.0088	8.1679	8.3175	8.4593	8.5942	8.7231	8.8467
250 (127.43)	V	1.068	718.44	1051.6	1145.2	1238.5	1331.5	1424.4	1517.2	1609.9	1702.5
	U	535.077	2536.8	2808.0	2886.5	2966.3	3047.6	3130.4	3214.9	3301.1	3389.0
	H	535.343	2716.4	3070.9	3172.8	3275.9	3380.4	3486.5	3594.2	3703.6	3814.6
	S	1.6071	7.0520	7.7891	7.9597	8.1188	8.2686	8.4104	8.5453	8.6743	8.7980
275 (130.60)	V	1.071	657.04	955.45	1040.7	1125.5	1210.2	1294.7	1379.0	1463.3	1547.6
	U	548.564	2540.0	2807.5	2886.2	2966.0	3047.3	3130.2	3214.7	3300.9	3388.8
	H	548.858	2720.7	3070.3	3172.4	3275.5	3380.1	3486.2	3594.0	3703.4	3814.4
	S	1.6407	7.0201	7.7444	7.9151	8.0744	8.2243	8.3661	8.5011	8.6301	8.7538
300 (133.54)	V	1.073	605.56	875.29	953.52	1031.4	1109.0	1186.5	1263.9	1341.2	1418.5
	U	561.107	2543.0	2807.1	2885.8	2965.8	3047.1	3130.0	3214.5	3300.8	3388.7
	H	561.429	2724.7	3069.7	3171.9	3275.2	3379.8	3486.0	3593.7	3703.2	3814.2
	S	1.6716	6.9909	7.7034	7.8744	8.0338	8.1838	8.3257	8.4608	8.5898	8.7135

2014

Midterm

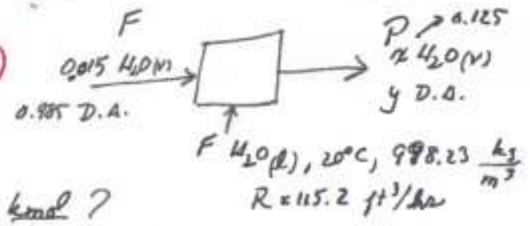
ENT NAME: SOLUTIONS ID#

CHEMICAL ENGINEERING 200 Mid-Term
Test: Oct. 29, 2014.
80 minutes (8:05 am-9:25 am)

SPECIAL INSTRUCTIONS: *This is a closed book test. You are permitted only the equation sheet (Appendix I attached) provided to you with the test, plus the compressibility charts and Appendix B from Felder and Rousseau. You may use the least-squares feature on your calculator to aid you in answering any linear fitting equations if not specified otherwise. Please answer in the space provided. Sloppy, disorganized work may not be graded. Justify clearly any assumptions you make and provide the source of any data you use which is not supplied. Final answers should be provided with the correct number of significant digits.* **This test consists of four questions on 8 pages and 30 points.** *Please bring any discrepancy to the attention of the invigilator – you are responsible for ensuring your test is complete.*

Problem 1 (5 points): Some humid air (composition 1.50 mol% water vapour with the balance dry air) is passed through a humidifier to produce air that contains 12.5 mol% water vapour). To achieve this humidification, water (liquid) is fed into the unit at 20 °C (density of water = 998.23 kg·m³ at 20 °C, and evaporated into the air stream. A rotameter is used to calibrate the liquid flow, with a reading of R = 115.2. You have only two points to calibrate the rotameter: at R = 20.0, flow rate = 50.0 ft³·h⁻¹ and at R = 60.0, flow rate = 104.0 ft³·h⁻¹. Draw and label a flow chart for this process and determine the molar flow rate (in units of kmol·h¹) of the humidified air exiting the unit.

for drawing ①



R	$\dot{V}$ (ft³/h)
20.0	50.0
60.0	104.0

interpolate or use regression.

What is $P\,[=]\,\frac{kmol}{h}$?

① Find flow rate of $H_2O(l)$: $\dot{V} = 1.35\left(115.2\,\frac{ft^3}{hr}\right) + 23.0\,\frac{ft^3}{h}$ $\dot{V} = 1.35R + 23.0$

$$\dot{V} = 178.52\ ft^3/h$$

now use density of $H_2O(l)$ @ 20°C and $MW_{H_2O} = 18\ g/mol$.

① $$F_{H_2O(l)} = \frac{\dot{V}\rho}{MW_{H_2O}} = \frac{178.52\ ft^3}{h}\cdot\frac{998.23\ kg}{m^3}\cdot\frac{kmol}{18\ kg}\cdot\frac{m^3}{(3.2808\ ft)^3} = 280\ \frac{kmol}{h}.$$

Do a dry air balance:

$$0.985F = (1-0.125)P \Rightarrow F = \frac{0.875}{0.985}P$$

① H_2O bal. $$0.015F + F_W = 0.125P$$

$$0.015\left(\frac{0.875}{0.985}\right)P + 280\,\frac{kmol}{h} = 0.125P$$

$$\therefore P = 280\,\frac{kmol}{h}\cdot\left\{\frac{1}{0.125 - 0.015\left(\frac{0.875}{0.985}\right)}\right\} = \underline{\underline{2.51\times10^{3}\ \frac{kmol}{h}}}$$ ①

STUDENT NAME: SOLUTIONS. **ID#**

Problem 2 (5 points): The phase diagram for carbon dioxide (CO_2) is provided below. Starting with the relevant form of the Clayperon equation shown below (Eq. 1), estimate the molar enthalpy of sublimation $\Delta\hat{H}_{sub}$, in units of kJ·mol^{-1}, for CO_2. Provide appropriate assumptions if you need to alter the equation to aid in your answer (Hint: you may use a simple equation of state for any vapour species). The specific volume change is $\Delta\hat{V}_{sub} = \hat{V}_g - \hat{V}_s$ where $\hat{V}_g$ is the specific molar volume of the vapour and $\hat{V}_s$ is the specific molar volume of the solid. P^* and T are the vapour pressure and temperature, respectively.

$$\frac{dP^*}{dT} = \frac{\Delta\hat{H}_{sub}}{T\Delta\hat{V}_{sub}} \qquad \text{(Eq. 1)}$$

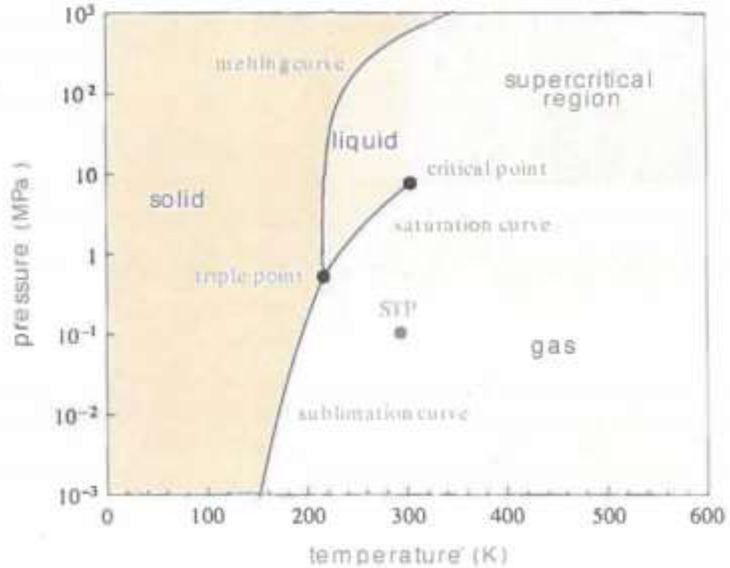


Figure 1: Phase diagram for CO_2 (courtesy of Wolfram Alpha).

assumption $\Delta\hat{V}_{sub} = \hat{V}_g - \hat{V}_s \cong \hat{V}_g \quad \hat{V}_g >> \hat{V}_s.$ (0.5)

Assume gas is ideal : $\hat{V}_g = \frac{RT}{P}$. (0.5)

$$\therefore \frac{dP^*}{dT} = \frac{\Delta\hat{H}_{sub}}{T\Delta\hat{V}_{sub}} = \frac{\Delta\hat{H}_{sub}}{T\hat{V}_g} = \frac{\Delta\hat{H}_{sub}}{RT^2}P^*$$

$$\therefore \frac{dP^*}{P} = \frac{\Delta\hat{H}_{sub}}{R}\frac{dT}{T^2} \quad \text{so} \quad \frac{d\ln P}{d(1/T)} = -\frac{\Delta\hat{H}_s}{R}$$ ①

Take 2pts: $P = 0.012$ MPa, $T = 180$ K
$P = 0.1$ MPa, $T = 200$ K
so slope $\approx \frac{\Delta \ln P}{\Delta 1/T}$ ①

$$\frac{d\ln P}{d\,1/T} \approx \frac{\ln 0.1 - \ln 0.012}{1/200 - 1/180} = -3.8\times 10^3\ \text{K}. \quad \therefore \Delta\hat{H}_s \approx 30\,\frac{kJ}{mol}$$ ① ①

STUDENT NAME: SOLUTIONS. **ID#**

Problem 3 (15 points): Methanol (CH_3OH) is produced from carbon monoxide (CO) and hydrogen (H_2), which are products obtained from the combustion of coal with steam. The process is shown below in *Figure 2*.

$$CO + 2H_2 \rightarrow CH_3OH$$

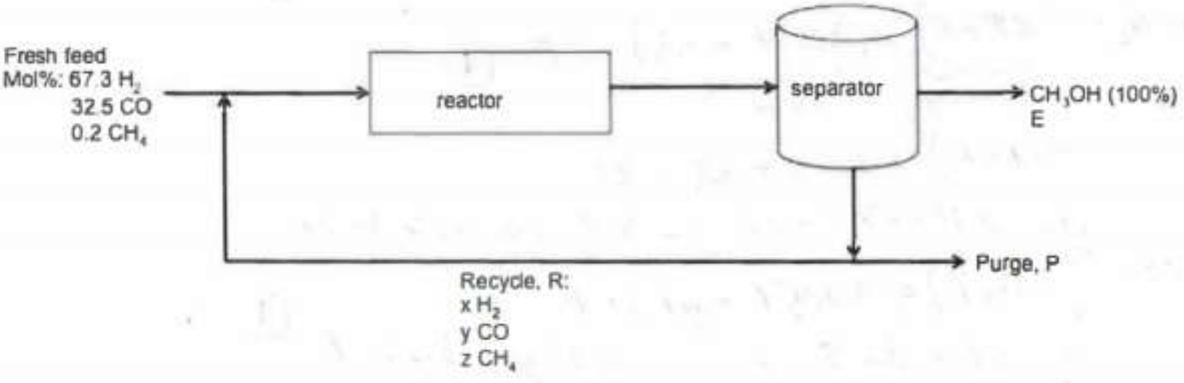


Figure 2: Methanol production process.

Some methane, like an inert, is present in the process, which does not participate in the reaction. It is desired to keep the methane concentration to not more than 3.2 mol% in the stream exiting the separator. A purge stream *P* is used to regulate this. You are provided that the single-pass CO conversion in the reactor is 18%. Determine the recycle flow rate *R*, the production of MeOH, *E*, the purge flow rate *P* and the composition of the purge gas stream. The mole fractions of H_2, CO and CH_4 in the recycle are given by *x*, *y*, and *z*, respectively.

CH_4 maximum conc. ⇒ $z = 0.032$ ① maximum permissible. This is CH_4 mol fraction in P+R.

$f_{CO} = 0.18$

Find: $R, E, P, \overset{H_2}{x}, \overset{CO}{y}, \overset{CH_4}{z}$.

Take $F = 100 \frac{mol}{h}$ feed basis ①

CH_4 is a "tie" component → it links together streams and doesn't participate in any reactions.

We can do a balance on CH_4 for the overall process:

$$0.002\,(100\ mol/h) = 0.032P$$
$$P = 6.25\ mol/h. \quad ①$$

now, we have 5 unknowns left R, E, x, y, z.

$z = 0.032$ (given constraint) so $x + y + 0.032 = 1$

We are now left with 4 unknowns.

We are given conversion for CO in the reactor.

$$f_{CO} = 0.18 = \frac{\text{mol reacted}}{\text{mol fed to reactor.}} = \frac{\xi}{32.5 + yR} = \frac{E}{32.5 + yR} \quad ①$$

E → mole reacted = mol CH_3OH formed.

STUDENT NAME: ID#

Around the reactor, we can write $n_{H_2} = n_{H_2,0} - 2\xi$ ①

$n_{CO} = n_{CO,0} - \xi$ ①

$n_{CH_3OH} = \xi = E.$ ①

For H_2: $\underbrace{x(P+R)}_{H_2 \text{ exiting}} = \underbrace{(0.673F + xR)}_{H_2 \text{ in}} - 2E$ ①

$x(P+R) = 67.3 + xR - 2E$

(1) $xP = 67.3 - 2E \implies 6.25x = 67.3 - 2E$

For CO: $y(R+P) = (0.325F + yR) - E$ ①

(2) $yP = 32.5 - E \qquad 6.25y = 32.5 - E$

From stoichiometry in recycle $x + y + 0.032 = 1$ (3). ①

I now have 3 equations in 3 unknowns and I can find R from the conversion data once I determine x, y, E.

Solve

Multiply (2) × 2 and then subtract from (1): ①

$6.25x - 12.5y = 2.3$

Use $y = 0.968 - x$ from recycle stream information.

$\therefore \quad 6.25x - 12.5(0.968 - x) = 2.3$

Solving $x = 0.768$ ①

$\therefore \quad y = 0.20$ ①

$\therefore E = 32.5 - 6.25y = 31.25 \frac{\text{mol}}{h}$ ①

From conversion data: $32.5 + yR = \frac{E}{0.18}$

$R = \left(\frac{E}{0.18} - 32.5\right)\frac{1}{0.20} = 706 \frac{\text{mol}}{h}.$ ①

$\therefore$

$R = 706$ mol/h $\qquad x = 0.768$

$E = 31.2$ mol/h $\qquad y = 0.200$

$P = 6.25$ mol/h $\qquad z = 0.032$

STUDENT NAME: SOLUTIONS. **ID#**

Problem 4 (5 points): A gaseous mixture (T = 25 °C, P = 125 atm) has the following composition (mol%):

C_2H_4	56.8
Ar	40.2
He	3.0

The experimentally determined molar volume is 0.15 L mol^{-1}. Using Kay's rule, determine how well your predicted molar volume matches the experimental one.

$$T_{c,Ar} = 150.69 K, \quad P_{c,Ar} = 47.99 \text{ atm}$$

For He, $P_c^a = P_c + 8$ atm $= 10.267$ atm and $T_c^a = 5.26$ K $+ 8$ K $= 13.26$ K.

apply Kay's rule: $P_{c,mix} = y_{C_2H_4} P_{c,C_2H_4} + y_{Ar} P_{c,Ar} + y_{He} P_{c,He}^a$

$$T_{c,mix} = y_{C_2H_4} T_{c,C_2H_4} + y_{Ar} T_{c,Ar} + y_{He} T_{c,He}^a$$

① $P_{c,mix} = 0.568 (50.5 \text{ atm}) + 0.402 (47.99 \text{ atm}) + 0.03 (10.26 \text{ atm}) = \underline{\underline{48.3 \text{ atm}}}$

① $T_{c,mix} = 0.568 (283.1 K) + 0.402 (150.69 K) + 0.03 (13.26 K) = \underline{\underline{221.8 K}}$

(0.5) $P_r = \dfrac{P}{P_{c,mix}} = \dfrac{125 \text{ atm}}{48.3 \text{ atm}} = 2.59$ (0.5) $T_r = \dfrac{T}{T_{c,mix}} = \dfrac{298 K}{221.8 K} = 1.34$

use compressibility charts (Fig. 5-4.3 from Felder + Rousseau)

$$z_m \approx 0.78$$

$$\hat{V}_{r,ideal} = 0.35 = \frac{P_{c,mix} \hat{V}}{R T_{c,mix}} \quad ①$$

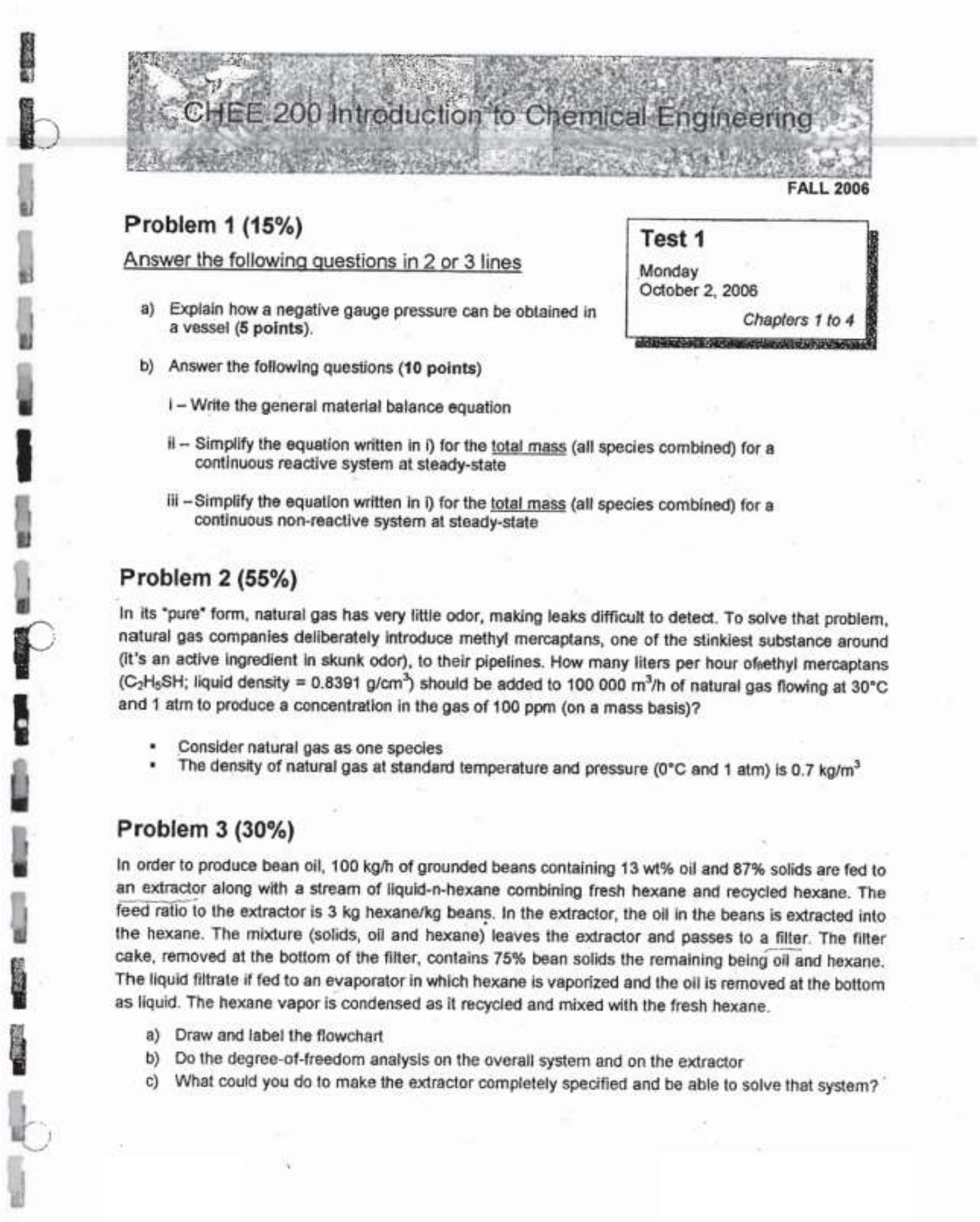
$$\hat{V} = \frac{R T_{c,mix}}{P_{c,mix}} \hat{V}_{r,ideal} = 0.08206 \frac{L \cdot atm}{mol\, K} \frac{221.8 K}{48.3 atm} (0.35) = \underline{\underline{0.13 \frac{L}{mol}}}$$

∴ $\hat{V}$ matches well with experimental value. (0.5)

$$\% \text{ deviation} = \frac{|0.02|}{0.15} \times 100\% = 12\%.$$

2006

Test 1



CHEE 200 Introduction to Chemical Engineering

FALL 2006

Test 1
Monday
October 2, 2006
Chapters 1 to 4

Problem 1 (15%)

Answer the following questions in 2 or 3 lines

a) Explain how a negative gauge pressure can be obtained in a vessel (**5 points**).

b) Answer the following questions (**10 points**)

i – Write the general material balance equation

ii – Simplify the equation written in i) for the total mass (all species combined) for a continuous reactive system at steady-state

iii – Simplify the equation written in i) for the total mass (all species combined) for a continuous non-reactive system at steady-state

Problem 2 (55%)

In its "pure" form, natural gas has very little odor, making leaks difficult to detect. To solve that problem, natural gas companies deliberately introduce methyl mercaptans, one of the stinkiest substance around (it's an active ingredient in skunk odor), to their pipelines. How many liters per hour of ethyl mercaptans (C_2H_5SH; liquid density = 0.8391 g/cm^3) should be added to 100 000 m^3/h of natural gas flowing at 30°C and 1 atm to produce a concentration in the gas of 100 ppm (on a mass basis)?

- Consider natural gas as one species
- The density of natural gas at standard temperature and pressure (0°C and 1 atm) is 0.7 kg/m^3

Problem 3 (30%)

In order to produce bean oil, 100 kg/h of grounded beans containing 13 wt% oil and 87% solids are fed to an extractor along with a stream of liquid-n-hexane combining fresh hexane and recycled hexane. The feed ratio to the extractor is 3 kg hexane/kg beans. In the extractor, the oil in the beans is extracted into the hexane. The mixture (solids, oil and hexane) leaves the extractor and passes to a filter. The filter cake, removed at the bottom of the filter, contains 75% bean solids the remaining being oil and hexane. The liquid filtrate if fed to an evaporator in which hexane is vaporized and the oil is removed at the bottom as liquid. The hexane vapor is condensed as it recycled and mixed with the fresh hexane.

a) Draw and label the flowchart
b) Do the degree-of-freedom analysis on the overall system and on the extractor
c) What could you do to make the extractor completely specified and be able to solve that system?

ICE tutorial 06/10/06

Midterm 1 correction

Problem 1

a) A negative gauge pressure can be obtained when a vacuum is created in a vessel by pumping the material that was inside a closed container.

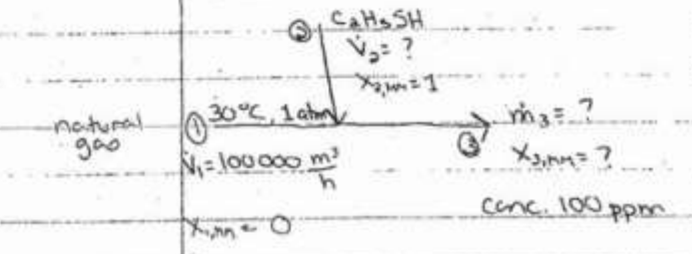
b) (i) input + generation - output - consumption = accumulation

do not apply to TOTAL MASS
reactive does not show up in total mass equation, you cannot create mass!

(ii) input - output = 0

(iii) input - output = 0

Problem 2



step 1 basis of 1 hour

step 2 see flow chart

step 3 $\rho_{NG}(0°C, 1\,atm) = 0.7\ kg/m^3$

assume ideal gas

$\hat{V}\left[\frac{m^3}{mol}\right] = \frac{MW}{\rho}$ $\qquad \hat{V} = \frac{RT}{P}$ $\qquad \rho = \frac{P(MW)}{RT}$ molecular weight

$$\frac{\rho(T_1)}{\rho(T_2)} = \frac{T_2}{T_1} \qquad \rho(30°C) = \frac{\rho(0°C)\ 273k}{303k} = \frac{0.7 \cdot 273}{303}$$

$$\rho(30°C) \cong 0.63\ kg/m^3$$

$\dot{m}_1 = 100\,000 \frac{m^3}{h} \cdot 0.63 \frac{kg}{m^3} = 63\,069 \frac{kg}{h}$

STEP 5 3 unknowns ($m_2, m_3, X_{3,MM}$)

2 ind. mat. bal. (NG, MM)

$\underline{1 \text{ conc.}}$

0

STEP 6 total mass

$m_1 + m_2 = m_3$

$63069 + m_2 = m_3$ Ⓐ

MM

C_2H_5SH $m_2 = m_3 X_{3,MM}$ Ⓑ

conc. $\frac{m_3 X_{3,MM}}{m_3} = 100 \cdot 10^{-6}$ Ⓒ

B into C $\frac{m_2}{m_3} = 100 \cdot 10^{-6} \Rightarrow m_2 = 100 \times 10^{-6} m_3$ Ⓓ

D in A $63069 + 100 \times 10^{-6} m_3 = m_3$

$m_3 = 63075$ kg Ⓔ

E in A $63075 - 63069 = 6.3$ kg

$m_2 = 6.3$ kg

STEP 8 $\dot{V}_2 = ?$

$= 6.3 \frac{kg}{h} \cdot \frac{cm^3}{0.8391 g} \cdot \frac{1000 g}{kg} \cdot \frac{1000 L}{10^6 cm^3}$

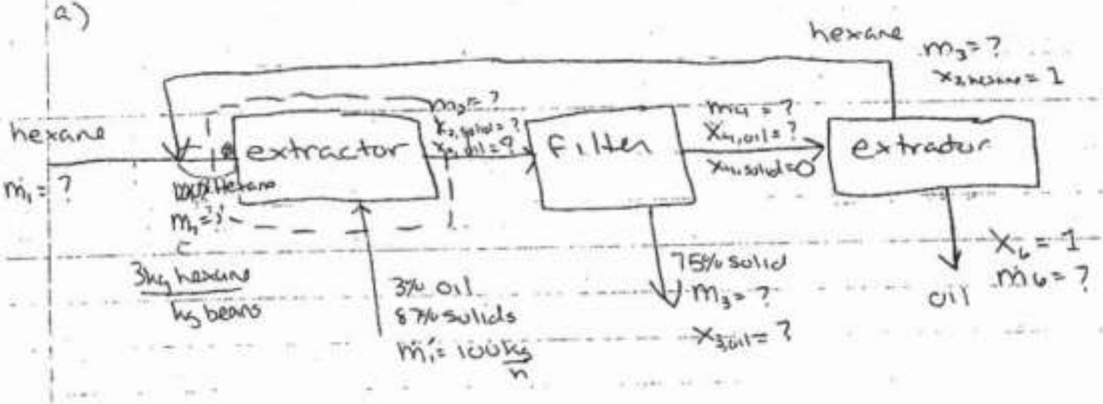
$= 7.5$ L/h

ICE tutorial 06/10/06

Midterm 1 Correction

Problem 3

a)



b) overall system

4 unknowns ($m_1, m_3, X_{3,oil}, m_6$)

3 mat bal (oil, hexane, liquid)

1

extractor

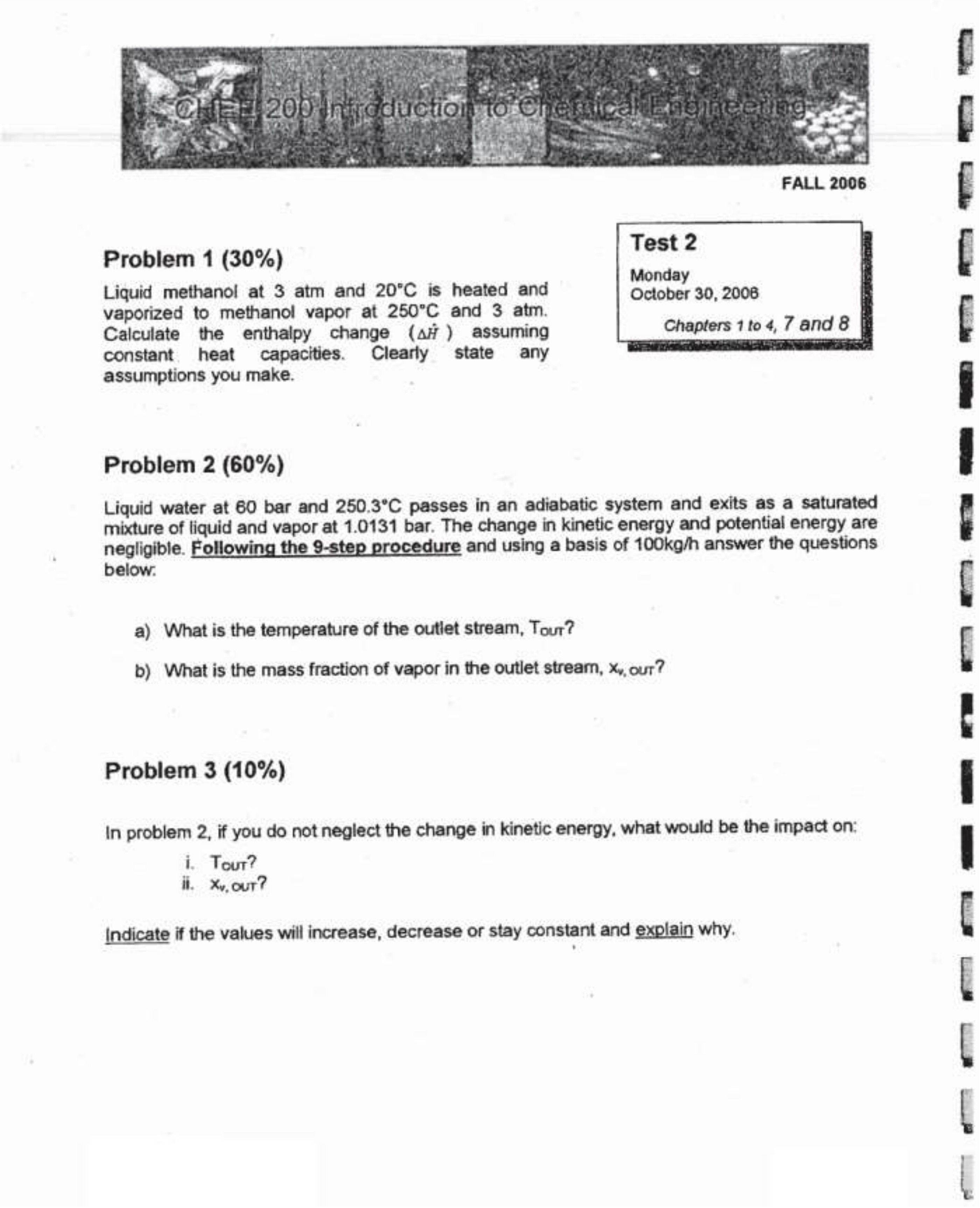
4 unknown ($m_2, X_{2,solid}, X_{2,oil}, m_7$)

3 ind mat bal (hexane, oil, solid)

1 ratio 3kg hexane/kg bean

0

Test 2



CHEE 200 Introduction to Chemical Engineering

FALL 2006

Test 2

Monday
October 30, 2006

Chapters 1 to 4, 7 and 8

Problem 1 (30%)

Liquid methanol at 3 atm and 20°C is heated and vaporized to methanol vapor at 250°C and 3 atm. Calculate the enthalpy change ($\Delta\hat{H}$) assuming constant heat capacities. Clearly state any assumptions you make.

Problem 2 (60%)

Liquid water at 60 bar and 250.3°C passes in an adiabatic system and exits as a saturated mixture of liquid and vapor at 1.0131 bar. The change in kinetic energy and potential energy are negligible. <u>**Following the 9-step procedure**</u> and using a basis of 100kg/h answer the questions below:

a) What is the temperature of the outlet stream, T_{OUT}?

b) What is the mass fraction of vapor in the outlet stream, $x_{v,OUT}$?

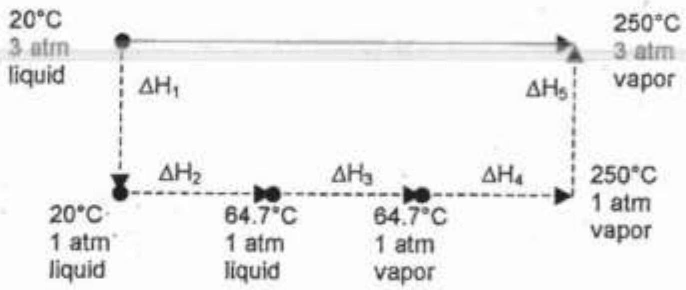
Problem 3 (10%)

In problem 2, if you do not neglect the change in kinetic energy, what would be the impact on:

i. T_{OUT}?
ii. $x_{v,OUT}$?

<u>Indicate</u> if the values will increase, decrease or stay constant and <u>explain</u> why.

Problem 1 – SOLUTION



T_b = 64.7°C from Table B.1

$$\Delta H_v = 35.27\frac{kJ}{mol}(Table B.1)$$

$\Delta H_1 \cong \hat{V}\Delta P$ (liquid)

$\Delta H_5 \cong 0$ (ideal gas)

$$\Delta\hat{H} = \Delta\hat{H}_1 + \Delta\hat{H}_2 + \Delta\hat{H}_3 + \Delta\hat{H}_4$$

$$\Delta\hat{H} = \hat{V}\Delta P + \int_{20}^{64.7} C_{P,liquid}\,dT + \Delta\hat{H}_{vap} + \int_{64.7}^{250} C_{P,vapor}\,dT$$

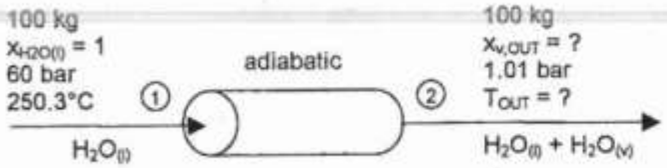
Use only the constant term for Cp, as mentioned in the problem statement

$$\boxed{\Delta\hat{H} = 46.61\frac{kJ}{mol}}$$

Problem 2 – SOLUTION (7.36)

STEP 1: Basis is 100 kg

STEP 2:



STEP 3: $T_{OUT} = ?$
$x_{2,v} = ?$

STEP 4: No conversion required

STEP 5: 2 unknowns (T_{OUT} and $x_{H2O(l),\,OUT}$)
1 material balance ($n_{ms} = 1$)
1 energy balance
0 → completely defined

STEP 6: $T_{OUT} = T_{saturation}$ @ 1.0131 bar = 100 °C $\Rightarrow T_2 = T_{OUT} = 100°C$ a)

MASS BALANCE:

$$100\frac{kg}{h} = \dot{m}_{2,l} + \dot{m}_{2,v} \quad (1)$$

ENERGY BALANCE:

$$\dot{m}_{2,l}\hat{H}_{H2O(l)} + \dot{m}_{2,v}\hat{H}_{H2O(v)} - \dot{m}_1\hat{H}_{IN} = 0 \qquad (2)$$

STEP 7:

From Table B.6: $\hat{H}_{IN} = \hat{H}_{H2O,60bar,250.3°C} = 1087.4\frac{kJ}{kg}$

From Table B.5: $\hat{H}_{H2O(l),1.01bar,Tsat} = 419.1\frac{kJ}{kg}$ and $H_{H2O(v),1.01bar,Tsat} = 2676\frac{kJ}{kg}$

Combining material and energy balances: $m_{2,l} = 70.4\text{ kg}$ and $m_{2,v} = 29.6\text{ kg}$

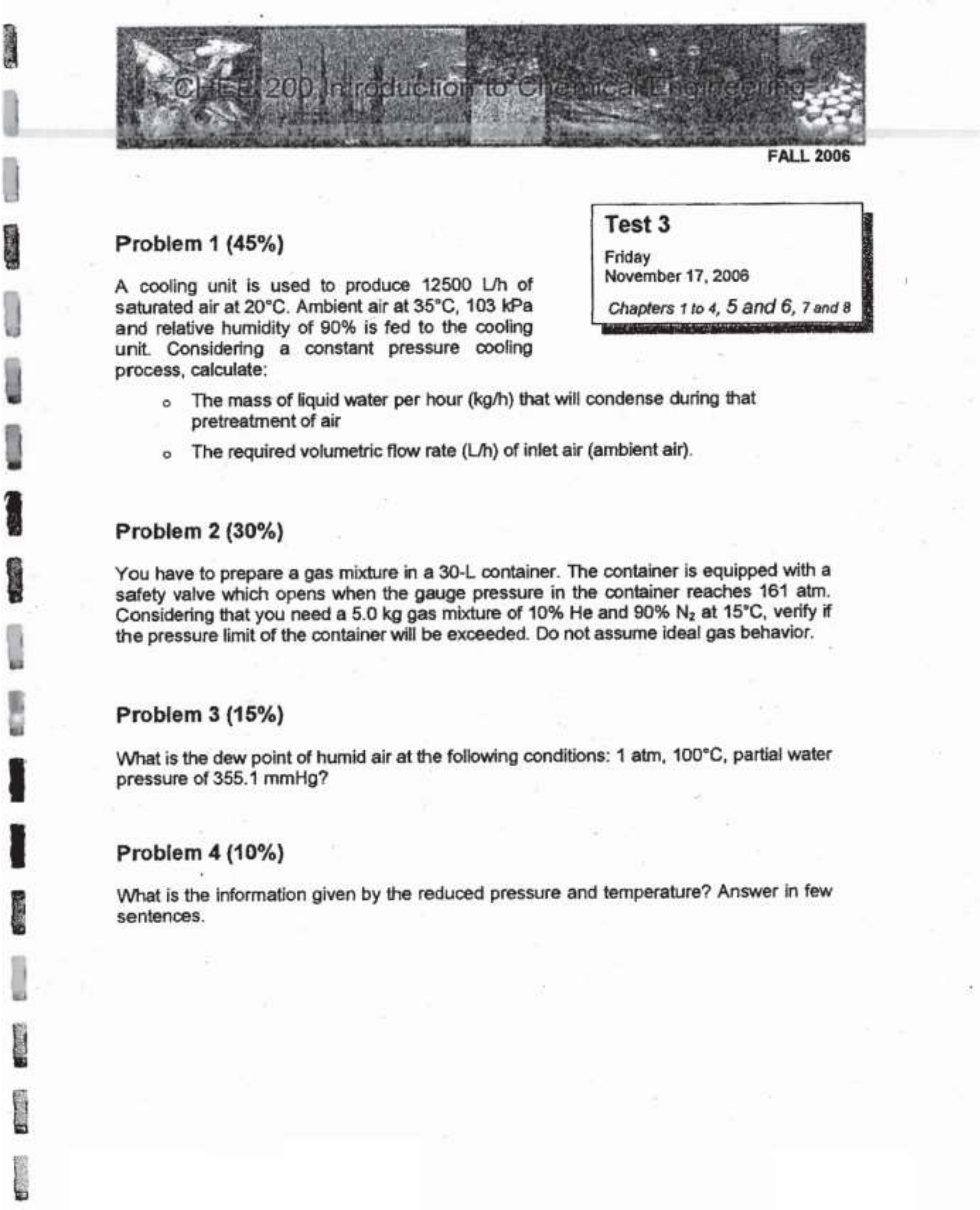
$$\Rightarrow x_{H2O(v),OUT} = x_{2,vapor} = \frac{29.6kgvapor}{100kg} = 0.296$$ b)

Problem 3 – SOLUTION

i) T is unchanged. The temperature will still be T saturation (same P)

ii) $x_{v,2}$ is smaller, less water would evaporate because some of the energy that would have vaporized the water was instead converted to kinetic energy. We know $\Delta\dot{E}_K > 0$ since the pressure decrease results in an expansion and vaporization (increase in velocity).

Test 3



CHEE 200 Introduction to Chemical Engineering

FALL 2006

Test 3

Friday
November 17, 2006

Chapters 1 to 4, 5 and 6, 7 and 8

Problem 1 (45%)

A cooling unit is used to produce 12500 L/h of saturated air at 20°C. Ambient air at 35°C, 103 kPa and relative humidity of 90% is fed to the cooling unit. Considering a constant pressure cooling process, calculate:

- The mass of liquid water per hour (kg/h) that will condense during that pretreatment of air
- The required volumetric flow rate (L/h) of inlet air (ambient air).

Problem 2 (30%)

You have to prepare a gas mixture in a 30-L container. The container is equipped with a safety valve which opens when the gauge pressure in the container reaches 161 atm. Considering that you need a 5.0 kg gas mixture of 10% He and 90% N_2 at 15°C, verify if the pressure limit of the container will be exceeded. Do not assume ideal gas behavior.

Problem 3 (15%)

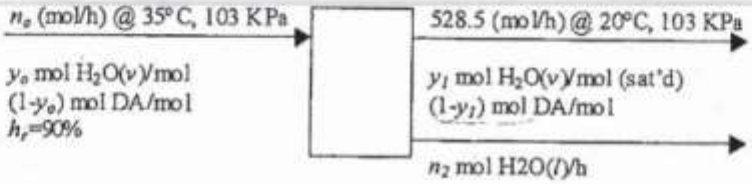
What is the dew point of humid air at the following conditions: 1 atm, 100°C, partial water pressure of 355.1 mmHg?

Problem 4 (10%)

What is the information given by the reduced pressure and temperature? Answer in few sentences.

Problem 1 (45%)

0.5 mol H₂O / mol



0.02270 mol H₂O / mol

Inlet:

$$y_0 = 0.4913 \frac{molH_2O}{mol}$$

Outlet:

$$y_1 = 0.02270 \frac{molH_2O}{mol}$$

571.6

Dry air balance:

$$n_0 = 543.2 \frac{mol}{h}$$

Inlet air: 13500 L/h

Total balance: $n_2 = 14.7 \frac{mol}{h}$

Condensation rate: 0.265 kg/h

Problem 2 (30%)

$$PV = z_m nRT$$

$$T_r = \frac{15+273.15}{114.9} = 2.50$$

$$V^{ideal}{}_r = \frac{\hat{V}P_c'}{RT_c'} = ?$$

$$\overline{MW} = 0.9 * 28.02 + 4 * .01 = 25.62$$

$$n = 5.0kg * \frac{1}{25.62\frac{kg}{kmol}} = 0.195kmol \Rightarrow \hat{V} = 0.154L/mol$$

Thus, $V^{ideal}{}_r = \frac{\hat{V}P'_c}{RT'_c} = \frac{0.154\frac{L}{mol}*31.2atm}{0.08206\frac{L\cdot atm}{mol\cdot K}*114.9K} = 0.51$

From Figure 5.4-3, $T_r = 2.50$ and $V_r^{ideal} = 0.51 \rightarrow z = 1.05$

$$P = \frac{z_m nRT}{V} = \frac{1.05*195mol*0.08206\frac{L\cdot atm}{mol\cdot K}*288.15K}{30L} = 161atm$$

$P_{gauge} = 160atm$ → the pressure limit will not be exceeded

Problem 3 (15%)

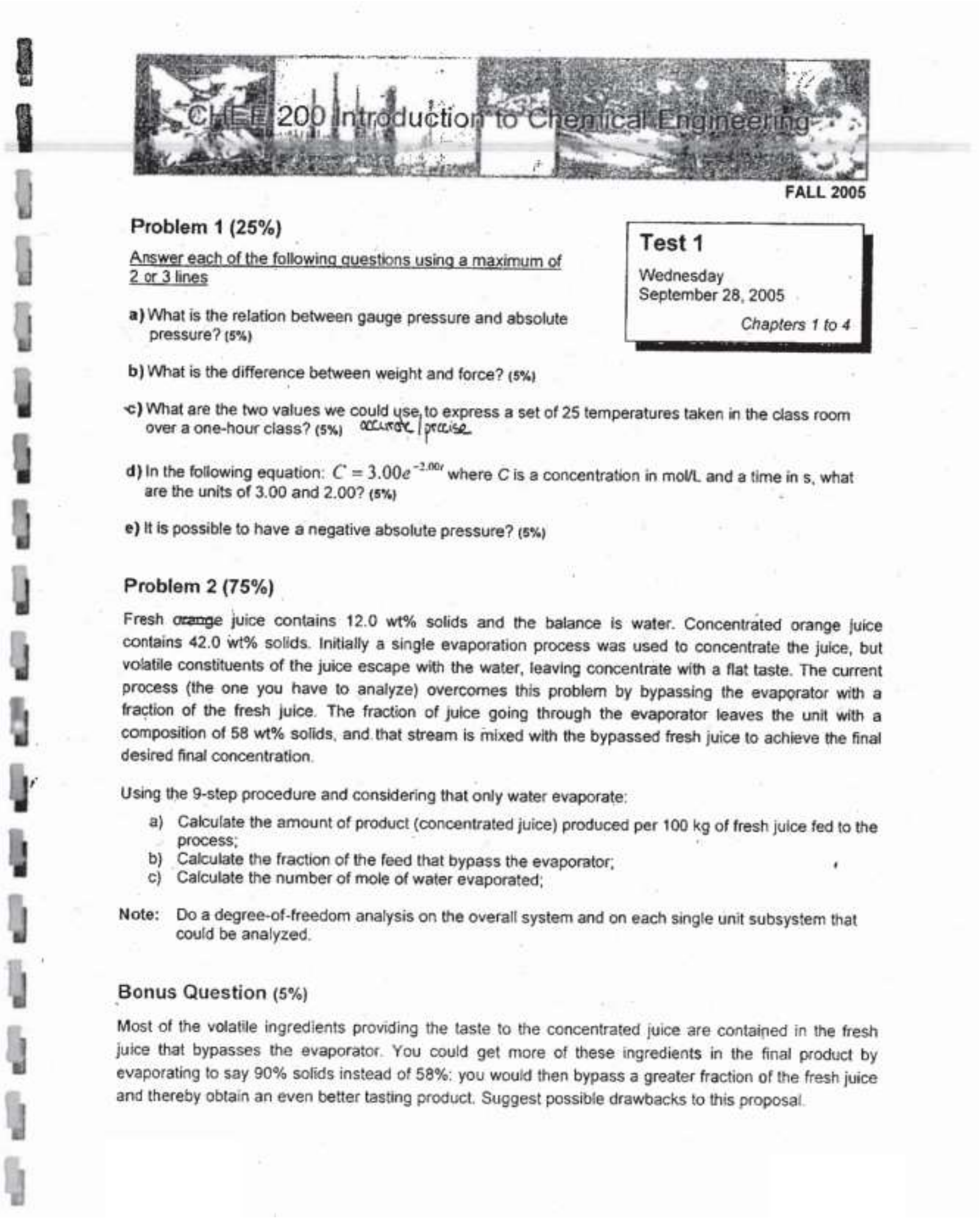
The dew point is when the vapor pressure is equal to the partial pressure of 355.1 mmHg. From table B.3, the temperature at which this happens is 80°C.

Problem 4 (10%)

They give an indication of the proximity of the gas to its critical state (T_c and P_c). Gases with the same proximity to the critical state have similar deviation from the ideal gas law.

2005

Test 1



CHEE 200 Introduction to Chemical Engineering

FALL 2005

Test 1

Wednesday
September 28, 2005

Chapters 1 to 4

Problem 1 (25%)

Answer each of the following questions using a maximum of 2 or 3 lines

a) What is the relation between gauge pressure and absolute pressure? **(5%)**

b) What is the difference between weight and force? **(5%)**

c) What are the two values we could use to express a set of 25 temperatures taken in the class room over a one-hour class? **(5%)** accurate | precise

d) In the following equation: $C = 3.00e^{-2.00t}$ where *C* is a concentration in mol/L and a time in s, what are the units of 3.00 and 2.00? **(5%)**

e) It is possible to have a negative absolute pressure? **(5%)**

Problem 2 (75%)

Fresh orange juice contains 12.0 wt% solids and the balance is water. Concentrated orange juice contains 42.0 wt% solids. Initially a single evaporation process was used to concentrate the juice, but volatile constituents of the juice escape with the water, leaving concentrate with a flat taste. The current process (the one you have to analyze) overcomes this problem by bypassing the evaporator with a fraction of the fresh juice. The fraction of juice going through the evaporator leaves the unit with a composition of 58 wt% solids, and that stream is mixed with the bypassed fresh juice to achieve the final desired final concentration.

Using the 9-step procedure and considering that only water evaporate:

a) Calculate the amount of product (concentrated juice) produced per 100 kg of fresh juice fed to the process;
b) Calculate the fraction of the feed that bypass the evaporator;
c) Calculate the number of mole of water evaporated;

Note: Do a degree-of-freedom analysis on the overall system and on each single unit subsystem that could be analyzed.

Bonus Question (5%)

Most of the volatile ingredients providing the taste to the concentrated juice are contained in the fresh juice that bypasses the evaporator. You could get more of these ingredients in the final product by evaporating to say 90% solids instead of 58%: you would then bypass a greater fraction of the fresh juice and thereby obtain an even better tasting product. Suggest possible drawbacks to this proposal.

Problem 1

a) gauge pressure + atmospheric pressure = absolute pressure

b) weight is the force of gravity acting on an object

c) mean and standard deviation

d) $3.00\ \frac{mol}{L}$ and $2.00\ s^{-1}$

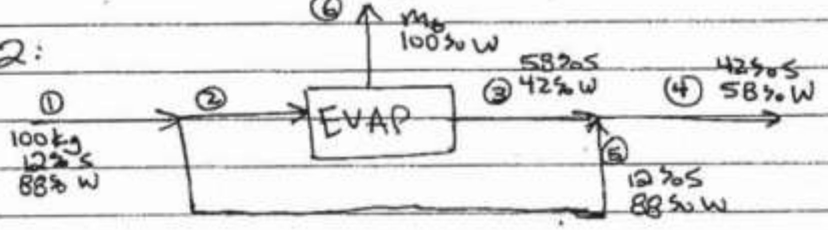
exponentials cannot have units, so in the exponen must be dimensionless

e) No

Problem 2

Step 1: basis of 100 kg

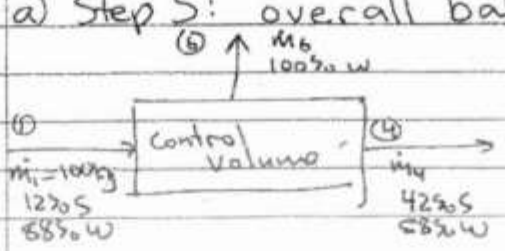
Step 2:



Step 3: a) $\dot{m}_4 = ?$ b) $\frac{\dot{m}_5}{\dot{m}_1} = ?$ c) $\dot{n}_6 = ?$

Step 4: all values in SI units already

a) Step 5: overall balance



$$\begin{array}{rl} 2 & \text{unknowns } (\dot{m}_4, \dot{m}_6) \\ -2 & \text{indep. mat. bal. (water, soli} \\ \hline 0 & \Leftarrow \text{completely specified.} \end{array}$$

Step 6:

TOTAL MASS BALANCE $m_1 = m_6 + m_4$

$100 = m_6 +$

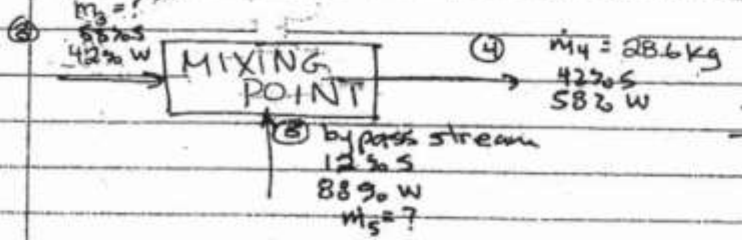
SOLIDS MASS BALANCE $m_1 x_{1,s} = m_4 x_{4,s}$

$100(0.12) = 0.42 m_4$

$12 = 0.42 m_4$

Step 7: $m_4 = \frac{12}{0.42} = \underline{\underline{28.6 \text{ kg}}}$

b) Step 5: balance on second mixing point



2 unknowns ($\dot m_3$, $\dot m_5$)

$\underline{-2}$ indep. mat. bal. (S, W

0 ⇐ completely specifie

Step 6:

TOTAL MASS BALANCE: $\dot m_3 + \dot m_5 = \dot m_4$ Ⓐ

SOLIDS MASS BALANCE: $0.58 \dot m_3 + 0.12 \dot m_5 = (0.42)(28.6 \text{ kg})$

$0.58 \dot m_3 + 0.12 \dot m_5 = 12.0 \text{ kg}$ Ⓑ

Step 7: $\dot m_3 = \frac{12 - 0.12 \dot m_5}{0.58} = 20.7 - 0.207 \dot m_5$ from Ⓑ

sub $\dot m_3 = 20.7 - 0.207 \dot m_5$ into Ⓐ

$(20.7 - 0.207 \dot m_5) + \dot m_5 = 28.6$

$0.793 \dot m_5 = 7.9$

$\dot m_5 = 9.96 \text{ kg}$

Step 8: $\frac{\dot m_5}{\dot m_1} = \frac{9.96 \text{ kg}}{100 \text{ kg}} = \underline{\underline{0.10}}$

c) from (a) we had the system of equations

$12 = 0.42\dot{m}_4$ $\quad 100 = \dot{m}_4 + \dot{m}_6$

$m_4 = 28.6\text{ kg}$

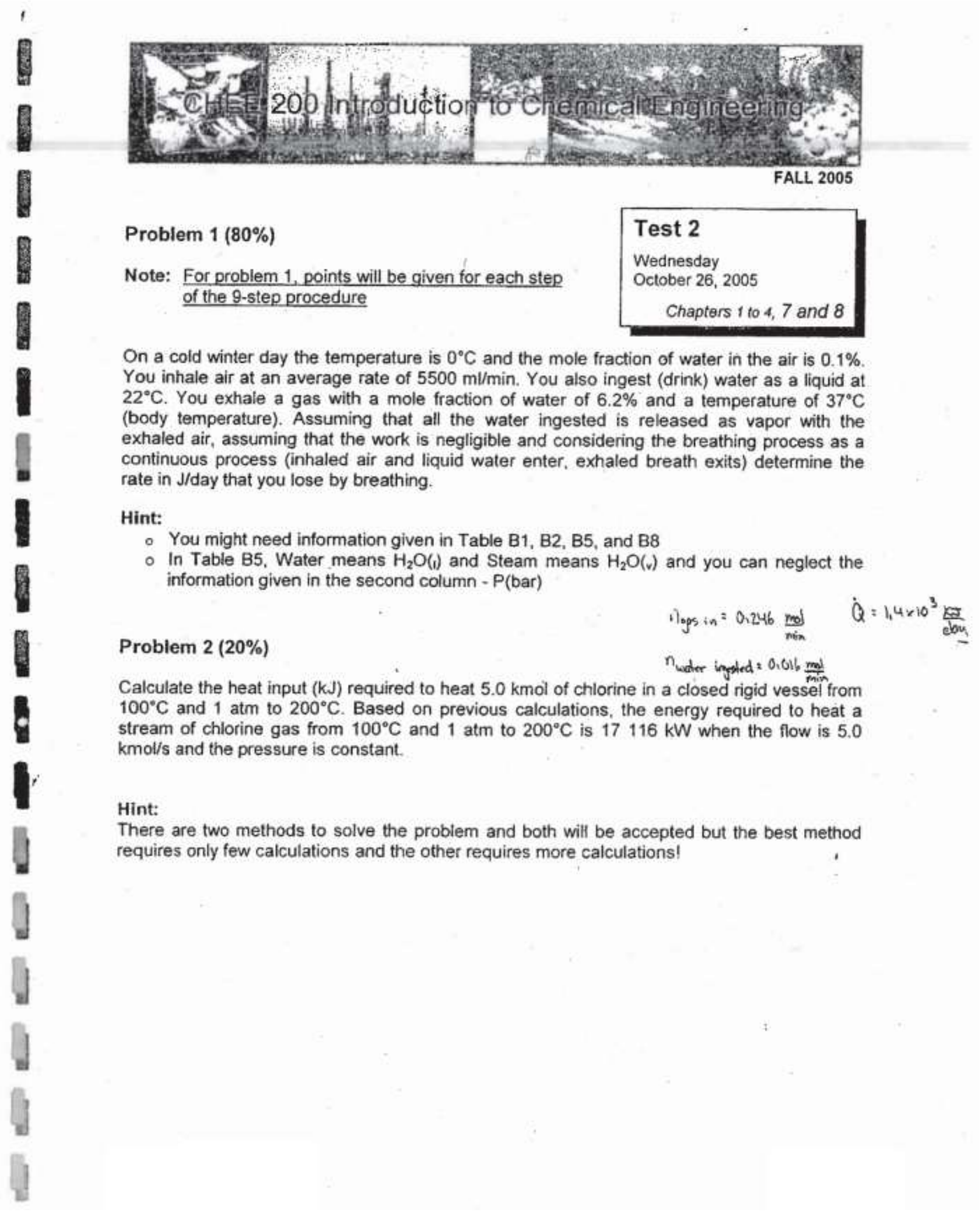
$\therefore 100 = 28.6 + \dot{m}_6$

$\dot{m}_6 = 71.4\text{ kg}$

want $\dot{n}_6 = (71.4\text{ kg})\left(\frac{1\text{ mol}}{18 \times 10^{-3}\text{ kg}}\right)$

$\dot{n}_6 = \underline{\underline{3967}}\text{ mol}$

Test 2



CHEE 200 Introduction to Chemical Engineering

FALL 2005

Test 2

Wednesday
October 26, 2005

Chapters 1 to 4, 7 and 8

Problem 1 (80%)

Note: For problem 1, points will be given for each step of the 9-step procedure

On a cold winter day the temperature is 0°C and the mole fraction of water in the air is 0.1%. You inhale air at an average rate of 5500 ml/min. You also ingest (drink) water as a liquid at 22°C. You exhale a gas with a mole fraction of water of 6.2% and a temperature of 37°C (body temperature). Assuming that all the water ingested is released as vapor with the exhaled air, assuming that the work is negligible and considering the breathing process as a continuous process (inhaled air and liquid water enter, exhaled breath exits) determine the rate in J/day that you lose by breathing.

Hint:

- You might need information given in Table B1, B2, B5, and B8
- In Table B5, Water means $H_2O_{(l)}$ and Steam means $H_2O_{(v)}$ and you can neglect the information given in the second column - P(bar)

$\dot{n}_{gas\ in} = 0{,}246\ \frac{mol}{min}$

$\dot{Q} = 1{,}4 \times 10^3\ \frac{kJ}{day}$

$n_{water\ ingested} = 0{,}016\ \frac{mol}{min}$

Problem 2 (20%)

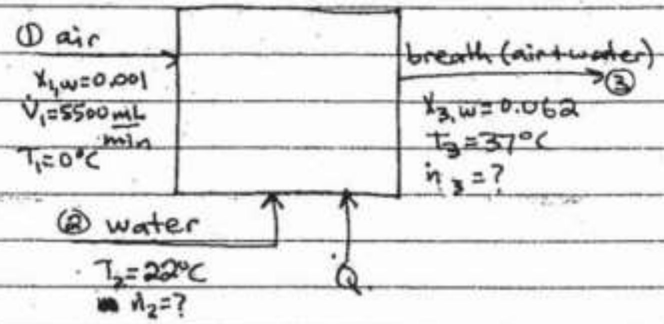
Calculate the heat input (kJ) required to heat 5.0 kmol of chlorine in a closed rigid vessel from 100°C and 1 atm to 200°C. Based on previous calculations, the energy required to heat a stream of chlorine gas from 100°C and 1 atm to 200°C is 17 116 kW when the flow is 5.0 kmol/s and the pressure is constant.

Hint:
There are two methods to solve the problem and both will be accepted but the best method requires only few calculations and the other requires more calculations!

Problem 1

Step 1: basis of 1 min

Step 2:



Step 3: $\dot{Q}$ in kJ/day

Step 4: $P\dot{V}_1=\dot{n}_1RT_1$

$$\dot{n}_1=\frac{P\dot{V}_1}{RT_1}=\frac{(1\ atm)(5.500\ \frac{L}{min})}{(0.08206\ \frac{L\cdot atm}{mol\cdot K})(273K)}=0.246\ mol/min$$

Step 5: 3 unknowns $(\dot{n}_2, \dot{n}_3, \dot{Q})$
- 2 indep. mat. bal. (air, water)
- 1 energy balance
0 ⇐ completely specified

Step 6: AIR BALANCE $x_{3,A}\dot{n}_3 = x_{1,A}\dot{n}_1$

TOTAL MOLE BALANCE $\dot{n}_3=\dot{n}_2+\dot{n}_1$

ENERGY BALANCE: $\dot{Q}-\cancel{\dot{W}_s}^{0}=\Delta\dot{H}+\cancel{\Delta\dot{E}_k}^{0}+\cancel{\Delta\dot{E}_p}^{0}$

assuming no acceleration, no changes in height and no shaft work

Step 7: material balances:

$(1-0.062)\dot{n}_3=(0.001)(0.246\ mol/min)$

$\dot{n}_3=0.262\ mol/min$

$\dot{n}_2 = \dot{n}_3 - \dot{n}_1 = 0.262 - 0.246$

$\dot{n}_2 = 0.016$ mol/min

energy balance $\dot{Q} = \Delta\dot{H} = \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$

standard states : H_2O (liquid, 0°C)

air (vapour, 0°C)

Stream	species	n_{in} (mol)	$\hat{H}_{in}$ ($\frac{kJ}{mol}$)	n_{out} (mol)	$\hat{H}_{out}$ ($\frac{kJ}{mol}$)
1	air (0°C, v)	0.2457	0	–	
1	water (0°C, v)	2.46×10^{-4}	45.09	–	
2	water (22°C, l)	0.016	1.66	–	
3	air (37°C, v)	–	–	0.2457	1.06
3	water (37°C, v)	–	–	0.0162	46.24

$\hat{H}_{1,air} = 0$ (standard state)

$\hat{H}_{1,water} = \left(2505.2 \frac{kJ}{kg}\right)\left(\frac{18\times10^{-3} kg}{mol}\right) = 45.09$ kJ/mol

↖ heat of vaporization of water at 0°C (Table B.5

$\hat{H}_{3,air} = \int_{T_{ref}}^{T_3} C_p dT = \int_0^{37} 28.64\times10^{-3} \frac{kJ}{mol\cdot{}^\circ C} dT$

$= \left(28.64\times10^{-3} \frac{kJ}{mol\cdot{}^\circ C}\right)(37°C)$

$= 1.06$ kJ/mol

$\dot{Q}$

$= \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$

$= (0.2457 mol)(1.06 \frac{kJ}{mol}) + (0.0162 mol)(46.24 \frac{kJ}{mol}) - (2.46\times10^{-4} mol)(45.09$

$- (0.016 mol)(1.66 \frac{kJ}{mol}) - (0.2457 mol)(0 \frac{kJ}{mol})$

$= 0.972$ kJ/min

Step 8: $Q = \left(\frac{0.972 kJ}{min}\right)\left(\frac{60 min}{hour}\right)\left(\frac{24 hours}{day}\right)$

$Q = 1.4\times10^3 \frac{kJ}{day}$

Problem 2

at 100°C to 200°C, Cl is always vapour so no phase change is observed

↳ heat supplied goes to changing temp.

want $Q_1 = \Delta U = n\,\Delta\hat{U} = n\int_{100°C}^{200°C} C_v\,dT$

given $Q_2 = \Delta\dot{H} = \dot{n}\,\Delta\hat{H} = \dot{n}\int_{100°C}^{200°C} C_p\,dT = 17116\text{ kW}$

$\dot{n} = 5\text{ kmol/s}$

$$\int_{100°C}^{200°C} C_p\,dT = \frac{17116\text{ kW}}{5\text{ kmol/s}} = 3423.2\,\frac{\text{J}}{\text{mol}}$$

$$\int_{100°C}^{200°C} C_p\,dT = \int_{100}^{200} (C_v + R)\,dT$$

$$3423.2\,\frac{\text{J}}{\text{mol}} = \int_{100}^{200} C_v\,dT + \int_{100}^{200} R\,dT$$

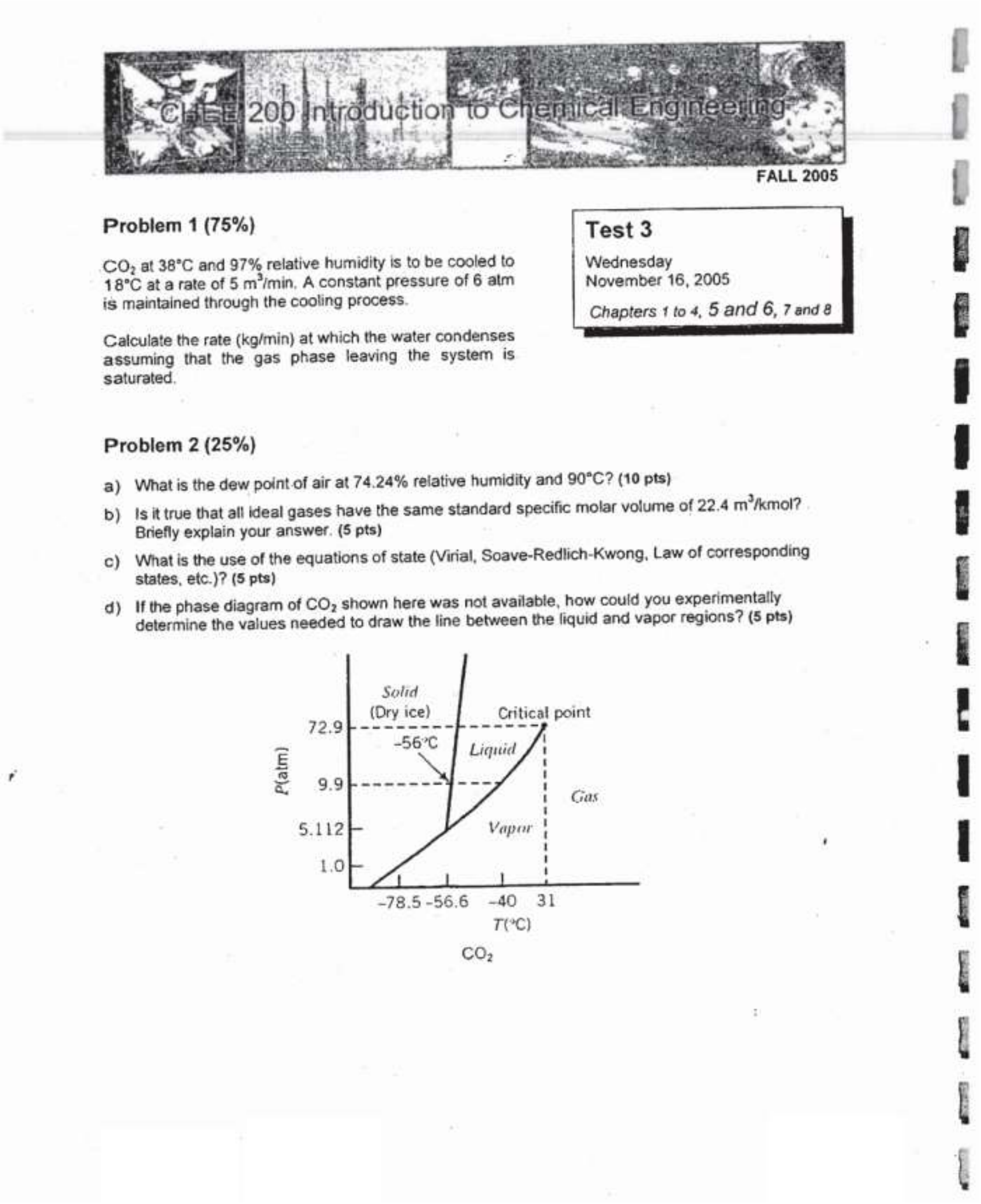
$$3423.2\,\frac{\text{J}}{\text{mol}} = \int_{100}^{200} C_v\,dT + \left(8.314\,\frac{\text{J}}{\text{mol}\cdot\text{K}}\right)(200°C - 100°C)$$

$$\int_{100}^{200} C_v\,dT = 2591.8\text{ J/mol}$$

$$\therefore\ Q_1 = \left(2591.8\,\frac{\text{J}}{\text{mol}}\right)(5\times10^3\text{ mol})$$

$$Q_1 = 12.96\text{ MW} = 1.296\times10^7\text{ W}$$

Test 3



CHEE 200 Introduction to Chemical Engineering

FALL 2005

Test 3

Wednesday
November 16, 2005

Chapters 1 to 4, 5 and 6, 7 and 8

Problem 1 (75%)

CO_2 at 38°C and 97% relative humidity is to be cooled to 18°C at a rate of 5 m^3/min. A constant pressure of 6 atm is maintained through the cooling process.

Calculate the rate (kg/min) at which the water condenses assuming that the gas phase leaving the system is saturated.

Problem 2 (25%)

a) What is the dew point of air at 74.24% relative humidity and 90°C? **(10 pts)**

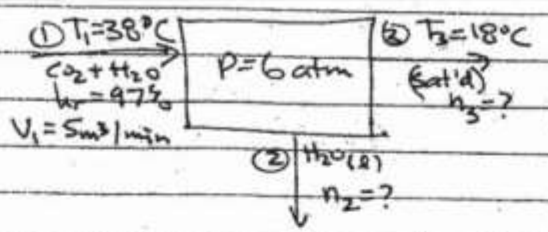
b) Is it true that all ideal gases have the same standard specific molar volume of 22.4 m^3/kmol? Briefly explain your answer. **(5 pts)**

c) What is the use of the equations of state (Virial, Soave-Redlich-Kwong, Law of corresponding states, etc.)? **(5 pts)**

d) If the phase diagram of CO_2 shown here was not available, how could you experimentally determine the values needed to draw the line between the liquid and vapor regions? **(5 pts)**

CO_2

Problem 1



want $\dot{m}_2 = ?$

$y_{1,H_2O} = ?$

$p^*_{H_2O}(38°C) = 0.0662 \text{ bar} = 0.0653 \text{ atm}$

$$0.97 = \frac{y_i P}{p^*_{H_2O}(38°C)} \Rightarrow y_i = \frac{0.97(0.0653 \text{ atm})}{6 \text{ atm}}$$

$\underline{y_{1,H_2O} = 0.011}$

$y_{3,H_2O} = ?$

$p^*_{H_2O}(18°C) = 0.0262 \text{ bar} = 0.0204 \text{ atm}$

Raoult's Law $y_{3,H_2O} P = p^*(18°C)$

$$y_{3,H_2O} = \frac{0.0204 \text{ atm}}{6 \text{ atm}} = \underline{3.39 \times 10^{-3}}$$

$n_1 = ?$

cannot use ideal gas law because of high pressure
↳ Law of Corresponding States

pseudocritical temp.: $T_c' = y_{H_2O} T_{c,H_2O} + y_{CO_2} T_{c,CO_2}$

$T_c' = (0.011)(647.4 K) + (0.989)(304 K)$

$T_c' = 307.8 K$

$$T_r = \frac{311 K}{307.8 K} = 1.0$$

pseudocritical pressure

$P_c' = (0.011)(218.3 \text{ atm}) + (0.989)(72.9 \text{ atm})$

$P_c' = 74.5 \text{ atm}$

$$P_r = \frac{6 \text{ atm}}{74.5 \text{ atm}} = 0.08$$

for $T_r = 1.0$ and $P_r = 0.08$ $z = 0.98$
from figure S4-2

$$n_1 = \frac{PV_1}{zRT} = \frac{(6\,atm)(5000\,L/min)}{(0.98)(0.08206\,\frac{L\cdot atm}{mol\cdot K})(311\,K)} = 1200\ mol/min$$

mole balances:
total - $n_1 = n_2 + n_3 \Rightarrow 1200 = n_2 + n_3$ ①
water - $0.011 n_1 = n_2 + (3.39\times10^{-3}) n_3$
$\hookrightarrow 13.2 = n_2 + (3.39\times10^{-3})n_3)$ ②

solving system of equations 1 + 2 gives
$n_2 = 9.2$ mol/min $n_3 = 1190.8$ mol/min

$$m_2 = \left(\frac{9.2\,mol}{min}\right)\left(\frac{18\times10^{-3}\,kg}{mol}\right)$$
$$m_2 = \underline{\underline{0.17\,kg/min}}$$

Problem 2

a) $0.7424 = \frac{p_i}{p^*(90°C)} \Rightarrow p_i = (0.7424)(525.76\,mmHg)$
$p_i = 390.32$ mmHg
$p^*_{H_2O}(T_{dp}) = 390.32$ mmHg $T = 82°C$ $p^* = 384.9$ mmHg
$T = 83°C$ $p^* = 400.6$ mmHg
using interpolation → $T_{dp} = \underline{\underline{82.3°C}}$

b) yes molar density depends on conditions not what the gas is
c) describe behaviour of non ideal gases
d) find pressure at which liquid and vapour CO_2 are at equilibrium for given temperatures.

Final

Examiners: Prof. Viviane Yargeau Viviane Yargeau
Associate Examiners: Prof. David Cooper for Prof. Cooper.

FALL 2005

Final exam

Wednesday, December 14, 2005; 9h00 to 12h00

Instructions:

This is an open book exam (books, notes or other material are allowed)
You should answer in the booklet provided
Faculty standard calculator permitted only

Problem 1 (20%)

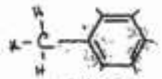
A 5.0-m^3 tank can be charged with 75.0 kg of benzene or toluene at 25°C.

*Ask Prof.

a) Using the Van der Waals equation of state, estimate the pressure in the tank when filled with i) pure toluene and ii) pure benzene.

b) Calculate the percentage error that would result from the use of the ideal gas equation of state for the calculation for each species and explain the relative magnitudes of calculated errors.

C_7H_8



toluene

benzene

C_6H_6

Problem 2 (30%)

A liquid species B is placed in a well-insulated container containing nitrogen, which is then sealed. Initially, the container and its contents (the B liquid and the pure nitrogen gas) are at 93°C and 1 atm; the liquid volume is 70 cm^3, and the gas volume is 3.00L. The liquid B partially evaporates, and the system cools down and eventually comes to thermal equilibrium at 85°C with liquid B still present. Physical property data for the species B are:

Species B:

$$\Delta\hat{U}_{vaporization} = 20\frac{kcal}{mol} \text{ at } 90°C$$

$$C_{p,liquid} = 20\frac{cal}{mol°C}$$

$$C_{p,vapor} = 10\frac{cal}{mol°C}$$

$$SG_{liquid} = 0.90$$

$$MW = 42$$

a) Determine $C_{v,liquid}$ and $C_{v,vapor}$

b) Draw and label a flowchart for this system and write and simplify the energy balance equation assuming adiabatic operation.

c) Use the energy balance to calculate the mass of liquid that evaporates.

d) Calculate the vapor pressure of the liquid at 85°C, assuming that the gas volume remains constant to 3.00L.

Problem 3 (25%)

It is desired to produce 10kW of refrigeration from a vapor-compression refrigeration cycle. The working fluid is refrigerant 125. The cycle operates between 25.7 kPa and 900 kPa. Assuming an efficiency of compression of 75%:

a) Determine the COP and compare it to the COP of a Carnot refrigerator

b) Determine the mass flow rate of refrigerant needed

c) Knowing that the ambient temperature is 25°C and that the temperature inside of the refrigerator must be 4°C, comment on the operation temperatures of the cycle.

d) Determine the temperature after the condenser and the temperature after the expansion valve.

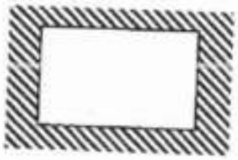
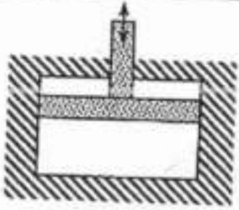
NOTE: Thermodynamic properties of refrigerant 125 are given in the Appendix.

Problem 4 (25%)

Using the 1st Law of thermodynamics, derive an equation to calculate the heat transferred to the following adiabatic systems to increase the temperature T_1 to a temperature T_2 (the same in all cases). The variables in the equation obtained must be limited to heat capacity, amount of material (mass or mole) and temperature.

C_p, m/n, temp

For each set of systems, predict if $Q_1 > Q_2$; $Q_1 \approx Q_2$ or $Q_1 < Q_2$ and justify your answer.

SET		**SYSTEM 1**	**SYSTEM 2**
1	Gas phase		
2	Liquid phase $T_2 < T_{\text{boiling point}}$		
3	Liquid phase $T_2 > T_{\text{boiling point}}$		

Note: Your results should include 6 equations (3 sets, 2 systems per set) and 3 justified predictions (1 per set).

APPENDIX

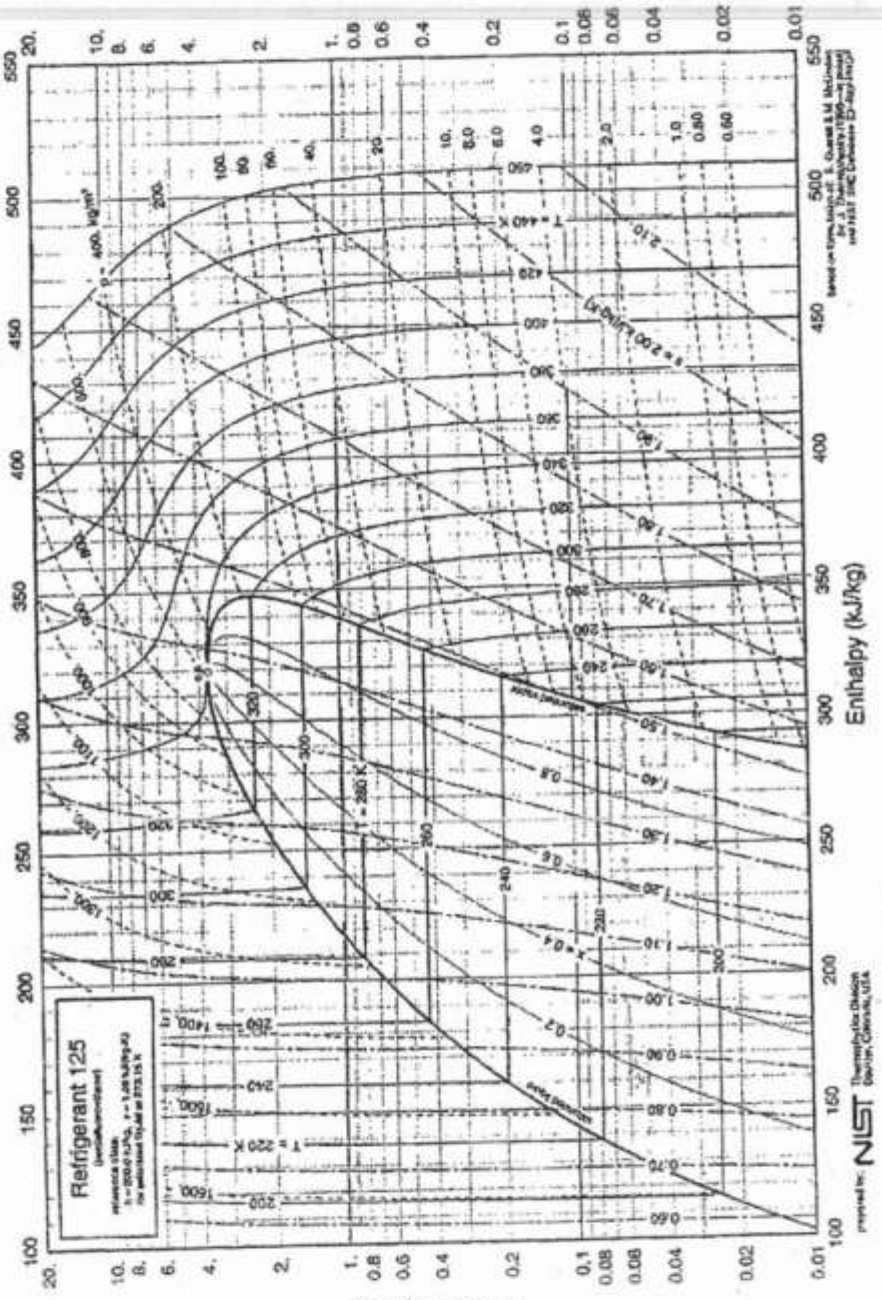


FIG. 2-26 Enthalpy-log pressure diagram for Refrigerant 125.

Final Exam 2005

$m = 75.0\ \text{kg}$

1. $V = 5.0\ m^3 = 5.0\times10^3 L$

$T = 25°C = 298\ K$ $\boxed{P = ?}$

$$P = \frac{RT}{\hat{V}-b} - \frac{a}{\hat{V}^2}$$

a) i) pure toluene

$$a = \frac{27R^2T_c^2}{64P_c^2} \quad b = \frac{RT_c}{8P_c}$$

$T_c = 593.9\ K$ $P_c = 40.3\ atm$

$$a = \frac{(27)(0.08206\frac{L\cdot atm}{mol\cdot K})^2(593.9k)^2}{(64)\ (40.3\ atm)^2} = 24.86\ \frac{L^2}{mol^2}$$

$$b = \frac{(0.08206\frac{L\cdot atm}{mol\cdot K})(593.9\ K)}{(8)40.3\ atm} = 0.1512\ \frac{L}{mol}$$

3.39 atm

$$\bar{n} = (75.0\ kg)\left(\frac{mol}{92.13\times10^{-3}\ kg}\right) = \underline{814.1\ mol}$$

$$\hat{V} = \frac{5.0\times10^3 L}{814.1\ mol} = 6.142\ \frac{L}{mol}$$

$$P = \frac{(0.08206\frac{L\cdot atm}{mol\cdot K})(298K)}{(6.142\ L/mol - 0.1512\ L/mol)} - \frac{24.86\ L^2/mol^2}{(6.142\ L/mol)^2}$$

$$P = 4.081\ atm - 0.659 = \underline{\underline{3.42\ atm}}$$

ii) pure benzene

4.13 atm

$T_c = 562.6\ K$ $P_c = 48.6\ atm$ $MW = 78.11$

$$n = (75.0\ kg)\left(\frac{mol}{78.11\times10^{-3}\ kg}\right) = \underline{960.2\ mol}$$

$$a = \left(\frac{27}{64}\right)\frac{(0.08206\frac{L\cdot atm}{mol\cdot K})^2(562.6K)^2}{(48.6\ atm)^2} = 18.50\ \frac{L^2}{mol^2}$$

$$b = \frac{(0.08206\frac{L\cdot atm}{mol\cdot K})(562.6\ K)}{8(48.6\ atm)} = 0.1187\ \frac{L}{mol}$$

$$\hat{V} = \frac{5.0\times10^3 L}{960.2\ mol} = \underline{5.207\ L/mol}$$

$$P = \frac{(0.08206\frac{L\cdot atm}{mol\cdot K})(298\ K)}{5.207\ L/mol - 0.1187\ L/mol} - \frac{18.50\ L^2/mol^2}{(5.207\ L/mol)^2}$$

$$P = 4.806\ atm - 0.682 = \underline{\underline{4.72\ atm}}$$

b) $P = \frac{nRT}{V}$ $\Rightarrow$ toluene: $P = \frac{(814.1\ mol)(0.08206\frac{L\cdot atm}{mol\cdot K})(298K)}{5.0\times10^3 L}$

$P = 3.98\ atm$

$$|\epsilon| = \frac{|3.98\ atm - 3.39\ atm|}{3.39\ atm} \approx 17.4\%$$

benzene: $P = \frac{(960.2\,mol)(0.08206\,\frac{L\cdot atm}{mol\cdot K})(298\,K)}{5\times10^{3}\,L}$

$P = 4.696$ atm

$|\epsilon| = \frac{|4.696\,atm - 4.13\,atm|}{4.13\,atm} \times 100\% \approx 13.7\%$

error due to attractions between molecules and space that molecules take up

↳ toluene more polar & bigger, so more attractive forces & more space taken up by molec

2.

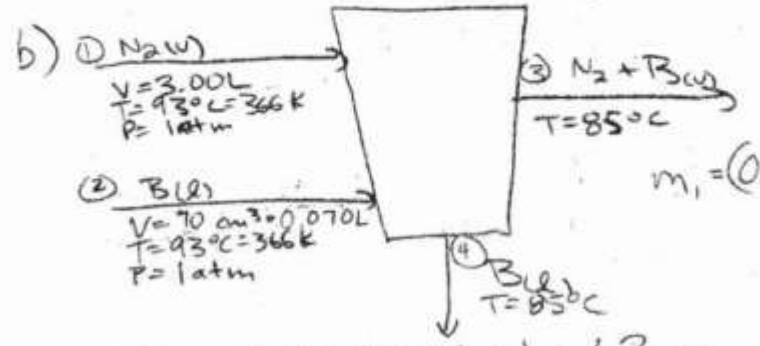
T=93°C
P= 1atm
$V_l = 70\,cm^3$
$V_g = 300L$

T=85°C

$Cp = Cv + R$

a) $C_{v,liquid} = C_{p,l} = 20$ cal / mol·°C
$C_{v,vapor} = C_{p,vap} - R = 10$ cal/mol·°C $- 1.987$ cal/mol·°C $= 8.013 \frac{cal}{mol\cdot\degree C}$

b)



$= \frac{RT}{P} \approx 30$

$PV = nRT$
$\frac{PV}{RT}$

$n_1 = \frac{(3.00\,L)(1\,atm)}{(0.08206\,\frac{L\cdot atm}{mol\cdot K})(366\,K)}$

$\boxed{n_1 = 0.100\,mol}$

$m_1 = (0.100\,mol)\left(\frac{28.02\times10^{-3}\,kg}{mol}\right) = 2.80\times1$ kg.

$\rho = SG\rho_{ref}$
$(0.90)\,1g/cm^3$

$m_2 = 70\,cm^3 \times (0.90\,g/cm^3) = 63\,g$

$n_2 = (63\,g)\left(\frac{mol}{42\,g}\right) = \boxed{1.5\,mol}$

		n	$\hat{U}$
IN	① N_2(v, 93°C, 1atm)	0.100	0
	② B(ℓ, 93°C, 1atm)	1.5	0
OUT	③ N_2(v, 85°C, ☐)	0.100	-39.8
	B(v, 85°C, ___)	1.5 - n	19900
	④ B(ℓ, 85°C, ___)	n	-160

set ref state
of B(ℓ, 93°C)
N_2 (v, 93°C)

$\hat{U}(B_{(\ell)} @ 85°C): \ \ell 93 \longrightarrow \ell 85$

$\Delta \hat{U} = \int_{93}^{85} C_{v,\ell}\, dT = \frac{20 \text{ cal}}{\text{mol}\cdot°C}[85°C - 93°C] = -160 \text{ cal/mol}$

$\hat{U}(B_{(v)} @ 85°C): \ \ell 93 \xrightarrow{①} \ell 90 \rightarrow v 90 \rightarrow v 85$

$\Delta \hat{U}_1 = \int_{93}^{90} C_{v\ell}\, dT = 20 \frac{\text{cal}}{\text{mol}\cdot°C}[90°C - 93°C] = -60 \text{ cal/mol}$

$\Delta \hat{U}_2 = +20 \text{ kcal/mol} = 20 \times 10^3 \text{ cal/mol}$

$\Delta \hat{U}_3 = \int_{90}^{85} C_{v_{vap}}\, dT = (8.013 \frac{\text{cal}}{\text{mol}\cdot°C})(85°C - 90°C) = -40.065 \text{ cal/mol}$

$\Delta \hat{U} = -60 \text{ cal/mol} + 20\times 10^3 \text{ cal/mol} - 40.065 \text{ cal/mol} = 19900$

$\hat{U}(N_{2(v)} @ 85°C) \quad v 93 \Rightarrow v 85$

$C_{v_{N_2}} = C_{p_{N_2}} - R = 29.00\times 10^{-3} + 0.2199\times 10^{-5} T + 0.5723\times 10^{-8} T^2 + D - 8.314$

$= 0.020686 + \cdots$

$\int_{93}^{85} 0.020686 \text{ kJ/mol}\cdot\text{K}\, dT = 0.020686(85-93) = -0.16655 \text{ kJ/mol}.$

$\left(\frac{-0.16655 \times 10^{3} \text{ J}}{\text{mol}}\right)\left(\frac{0.23901 \text{ cal}}{1 \text{ J}}\right) = -39.8 \text{ cal/mol}$

$\sum_{out} n\hat{U} - \sum_{in} n\hat{U} = 0 \Rightarrow (0.100)(-39.8) + (1.5-n)(19900) + n(-160) = 0$

$-3.98 + 29850 - 19900n - 160n = 0$

$29846 = 20060n \Rightarrow n = 1.48 \text{ mol}$

$0.49g\left(\frac{\text{mol}}{42g}\right)$

$m = (0.012 \text{ mol})\left(\frac{42 g}{\text{mol}}\right) = 0.51 g \Rightarrow 0.49 g$

$n = 0.0117 \text{ mol}$

d) $p^* = y_A P$

$n_{total}: 0.100 \text{ mol } N_2 + 0.012 \text{ mol } B = 0.112 \text{ mol}$

$\hat{V} = \frac{3.00 L}{0.112 \text{ mol}} = 26.8 \text{ L/mol} \Rightarrow$ ideal!

$P = \frac{nRT}{V} = \frac{(0.112 \text{ mol})(0.08206 \frac{L\cdot atm}{mol\cdot K})(358K)}{3.00 L} = 1.096 \text{ atm}$

$y = \frac{0.012}{0.112}$

$p^* = (0.107)(1.096) = 0.117 \text{ atm}$

$$Q - W_s = \Delta H + \Delta E_k + \Delta E_p \qquad C_v + R = C_p$$

$$C_v = C_p - R$$

system 1 system 2 $\underline{Q_2 > Q_1}$

4. set ① $Q_1 = \Delta U = m\int_{T_1}^{T_2} C_p - R\,dT \quad Q_2 = \Delta H = m\int_{T_1}^{T_2} C_p\,dT$

$$\boxed{Q_2 > Q_1}$$

set ②
$T_1 \to T_2$
liquid

$Q_1 = \Delta U \overset{c_v\ldots}{\approx} m\int_{T_1}^{T_2} C_p\,dT \quad Q_2 = \Delta H = m\int_{T_1}^{T_2} C_p\,dT$

$$\boxed{Q_2 \approx Q_1}$$

set ③
$T_1 \xrightarrow{1} T_{bp} \xrightarrow{2} T_{bp} \xrightarrow{3} T_2$
$l \quad l \quad v \quad v$

$$Q = \Delta U = U_1 + U_2 + U_3$$
$$= m\int_{T_1}^{T_{bp}} C_p\,dT + \underline{m(\Delta H_v - RT)} + m\int_{T_{bp}}^{T_2} C_p - R\,dT$$
$$= m\int_{T_1}^{T_{bp}} C_p\,dT + m(\Delta H_v - RT_{bp}) + m\int_{T_{bp}}^{T_2} C_p\,dT - m\int_{T_{bp}}^{T_2} R\,dT$$
$$= m\int_{T_1}^{T_2} C_p\,dT + m\,\Delta H_v - mRT_{bp} - mR[T_2 - T_{bp}]$$
$$= m\int_{T_1}^{T_2} C_p\,dT + m\,\Delta H_v - \cancel{mRT_{bp}} - mRT_2 + \cancel{mRT_{bp}}$$

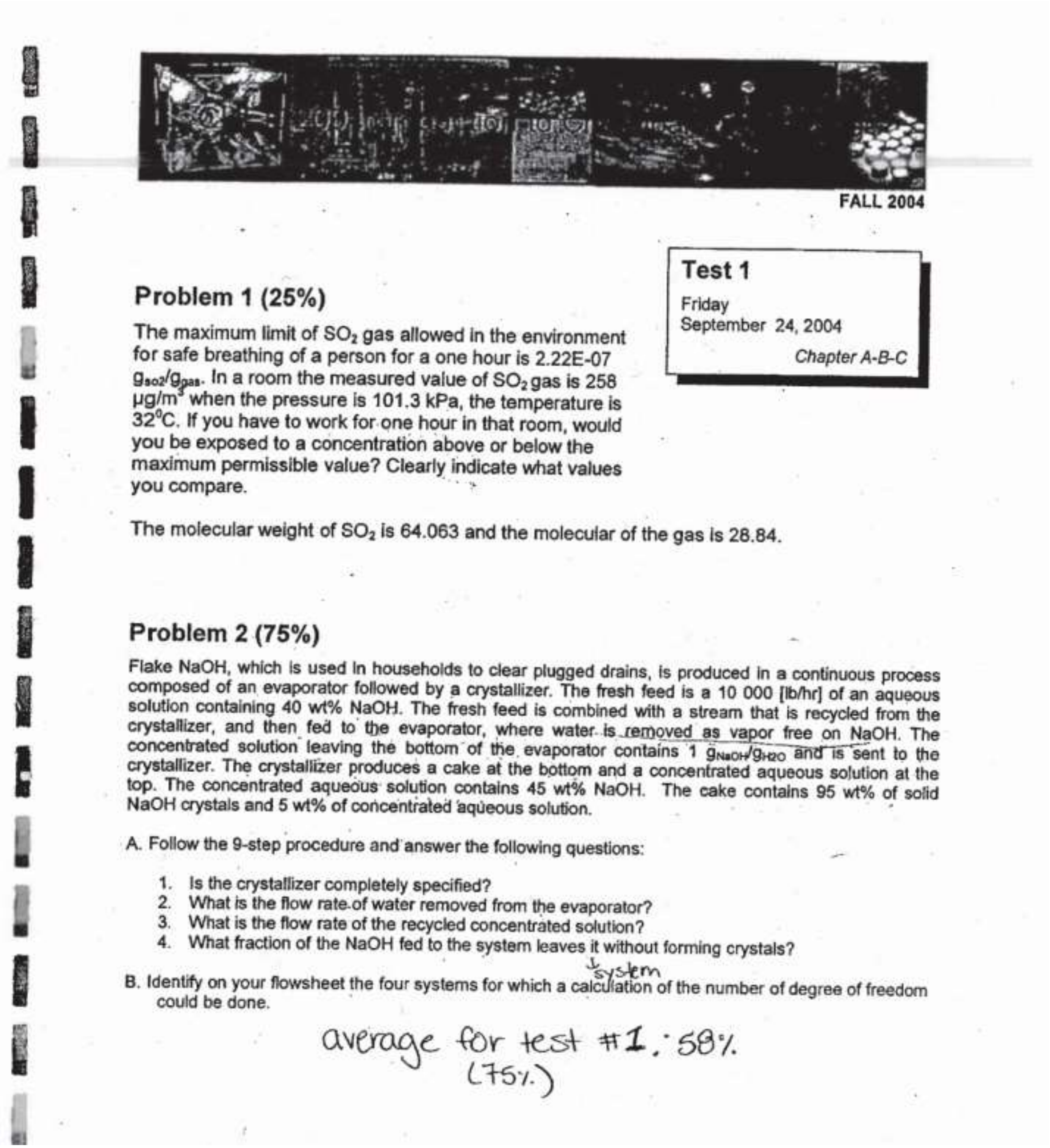
$$Q_1 = m\int_{T_1}^{T_2} C_p\,dT + m\,\Delta H_v - mRT_2$$

$$Q = \Delta H = H_1 + H_2 + H_3$$
$$= m\int_{T_1}^{T_{bp}} C_p\,dT + m\Delta H_v + m\int_{T_{bp}}^{T_2} C_p\,dT$$
$$Q_2 = m\int_{T_1}^{T_2} C_p\,dT + m\,\Delta H_v$$
$$Q_2 > Q_1$$

⇒ a) for gases : $Q_2 > Q_1$ since part of the energy is used to do work (expansion)
b) liquid only : no expansion ⇒ no W_s
c) same as (a)

2004

Test 1



FALL 2004

Test 1

Friday
September 24, 2004

Chapter A-B-C

Problem 1 (25%)

The maximum limit of SO_2 gas allowed in the environment for safe breathing of a person for a one hour is 2.22E-07 g_{so2}/g_{gas}. In a room the measured value of SO_2 gas is 258 $\mu g/m^3$ when the pressure is 101.3 kPa, the temperature is 32^0C. If you have to work for one hour in that room, would you be exposed to a concentration above or below the maximum permissible value? Clearly indicate what values you compare.

The molecular weight of SO_2 is 64.063 and the molecular of the gas is 28.84.

Problem 2 (75%)

Flake NaOH, which is used in households to clear plugged drains, is produced in a continuous process composed of an evaporator followed by a crystallizer. The fresh feed is a 10 000 [lb/hr] of an aqueous solution containing 40 wt% NaOH. The fresh feed is combined with a stream that is recycled from the crystallizer, and then fed to the evaporator, where water is removed as vapor free on NaOH. The concentrated solution leaving the bottom of the evaporator contains 1 g_{NaOH}/g_{H2O} and is sent to the crystallizer. The crystallizer produces a cake at the bottom and a concentrated aqueous solution at the top. The concentrated aqueous solution contains 45 wt% NaOH. The cake contains 95 wt% of solid NaOH crystals and 5 wt% of concentrated aqueous solution.

A. Follow the 9-step procedure and answer the following questions:

1. Is the crystallizer completely specified?
2. What is the flow rate of water removed from the evaporator?
3. What is the flow rate of the recycled concentrated solution?
4. What fraction of the NaOH fed to the system leaves it without forming crystals?

B. Identify on your flowsheet the four systems for which a $\overset{\downarrow \text{system}}{\text{calculation}}$ of the number of degree of freedom could be done.

average for test #1 : 58%
(75%)

ICE Test 1 2004

1) want to go from $\frac{ug}{m^3} \rightarrow \frac{g_{SO_2}}{g_{gas}}$

from $PV = nRT$

$$\text{limit} = 2.22 \times 10^{-7} \frac{g_{SO_2}}{g_{gas}} \times 28.84 \frac{g_{gas}}{gmol} \times \frac{P}{RT} \times \frac{gmol}{m^3}$$

$$R = 8.315 \frac{Pa}{m^3 \cdot K}$$

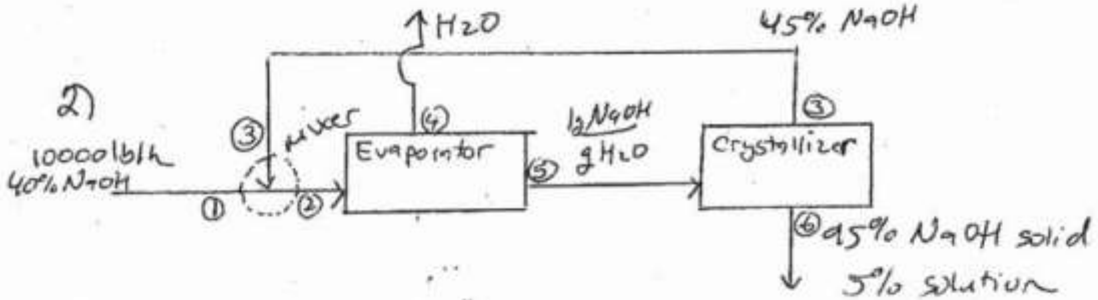
T in K

$$= 2.56 \times 10^{-4} \frac{g_{SO_2}}{m^3}$$

$$= 256 \frac{\mu g}{m^3}$$

$\therefore 258 \frac{\mu g}{m^3} > 256 \frac{\mu g}{m^3} \Rightarrow$ above limit!

2)



1. DoF

$N_v = 6$
$N_c = -2$
Zerocomp $= 0$
comp $= -3$
Flow $= \underline{0}$
1 $\therefore$ we need one more piece of informati

balance for crystallizer

H_2O $\quad 0.69 M^5 = (0.05)(0.55)(M^6) + 0.55 M3$

2. Overall balance

$10000(0.6) = M^4 + (0.05)(0.55)(M^6)$

and $\quad M^1 = M^4 + M^6$

$10000 = M^4 + M^6$

$6000 = M^4 + (0.05)(0.55)(10000 - M^4)$

$6000 = M^4 + (0.0275)(10000 - M^4)$

$\boxed{M^4 = 5887 \frac{lb}{h}}$ $\quad (M^6 = 4113 \, lb/h)$

3. Mixer

$M^1 + M^3 = M^2$

$10000 = M3 + M^2$

Evaporator

$M^2 = M^4 + M^5$

$M^2 = 5887 + M^5$

3 eqns, 3 unknowns

$M^2, M3, M^5$

⇒ solve

Crystallizer

$M^5 = M^3 + M^6$

$M^5 = M3 + 4113$

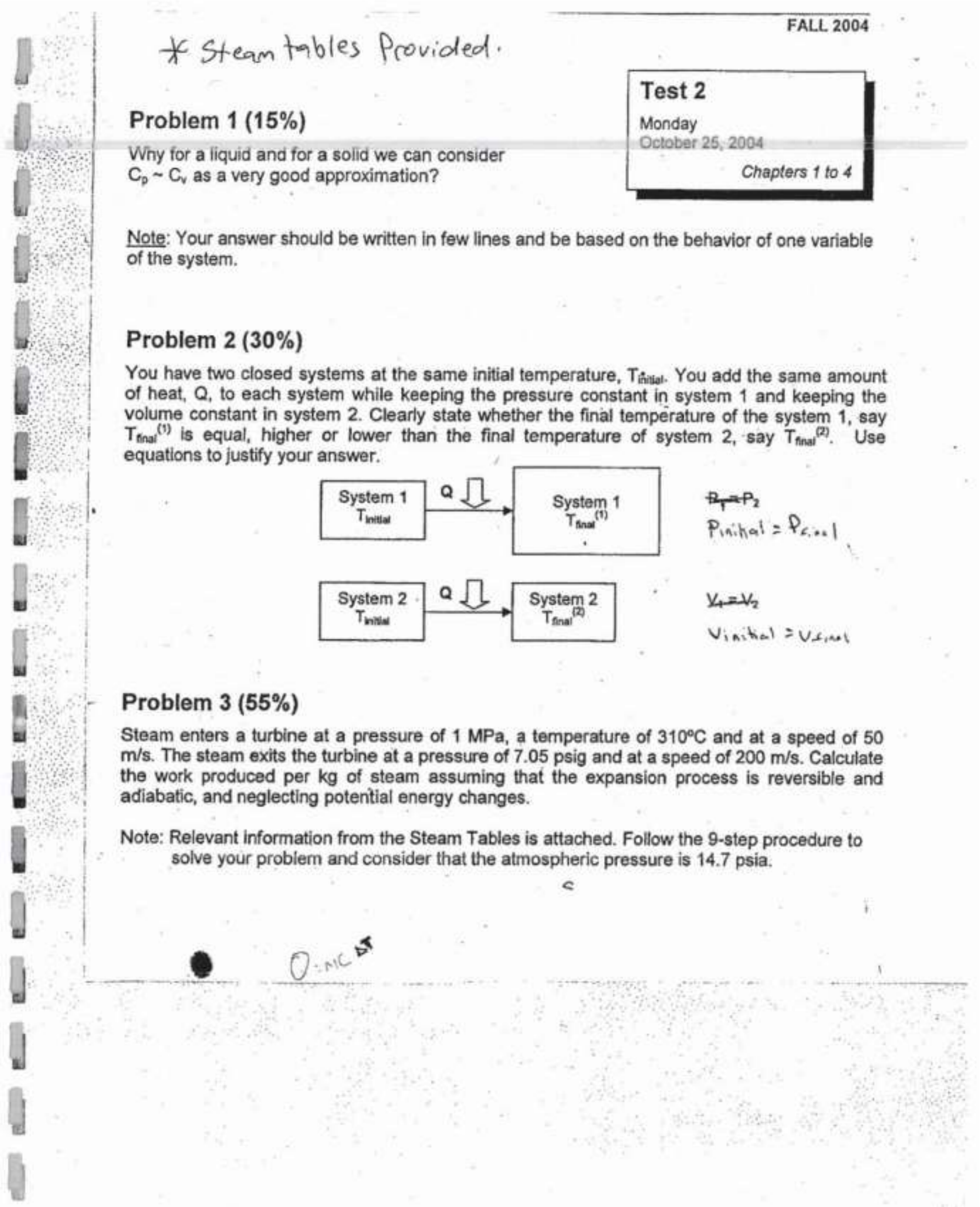
$\boxed{M3 = 38870 \, lb/h}$

4. amount not as crystals = amount of NaOH in sol'n

$\frac{\text{amount in sol'n}}{\text{amount in}} = \frac{(0.05)(0.45)(4113)}{(10000)(0.40)} = \boxed{2.3\%}$

B. Mixer, crystallizer, evaporator, overall

Test 2



FALL 2004

* Steam tables Provided.

Test 2

Monday

October 25, 2004

Chapters 1 to 4

Problem 1 (15%)

Why for a liquid and for a solid we can consider $C_p \sim C_v$ as a very good approximation?

Note: Your answer should be written in few lines and be based on the behavior of one variable of the system.

Problem 2 (30%)

You have two closed systems at the same initial temperature, $T_{initial}$. You add the same amount of heat, Q, to each system while keeping the pressure constant in system 1 and keeping the volume constant in system 2. Clearly state whether the final temperature of the system 1, say $T_{final}^{(1)}$ is equal, higher or lower than the final temperature of system 2, say $T_{final}^{(2)}$. Use equations to justify your answer.

System 1 $T_{initial}$ $\xrightarrow{Q}$ System 1 $T_{final}^{(1)}$

~~$P_1=P_2$~~

$P_{initial} = P_{final}$

System 2 $T_{initial}$ $\xrightarrow{Q}$ System 2 $T_{final}^{(2)}$

~~$V_1=V_2$~~

$V_{initial} = V_{final}$

Problem 3 (55%)

Steam enters a turbine at a pressure of 1 MPa, a temperature of 310ºC and at a speed of 50 m/s. The steam exits the turbine at a pressure of 7.05 psig and at a speed of 200 m/s. Calculate the work produced per kg of steam assuming that the expansion process is reversible and adiabatic, and neglecting potential energy changes.

Note: Relevant information from the Steam Tables is attached. Follow the 9-step procedure to solve your problem and consider that the atmospheric pressure is 14.7 psia.

$Q = mC\Delta T$

Test 2

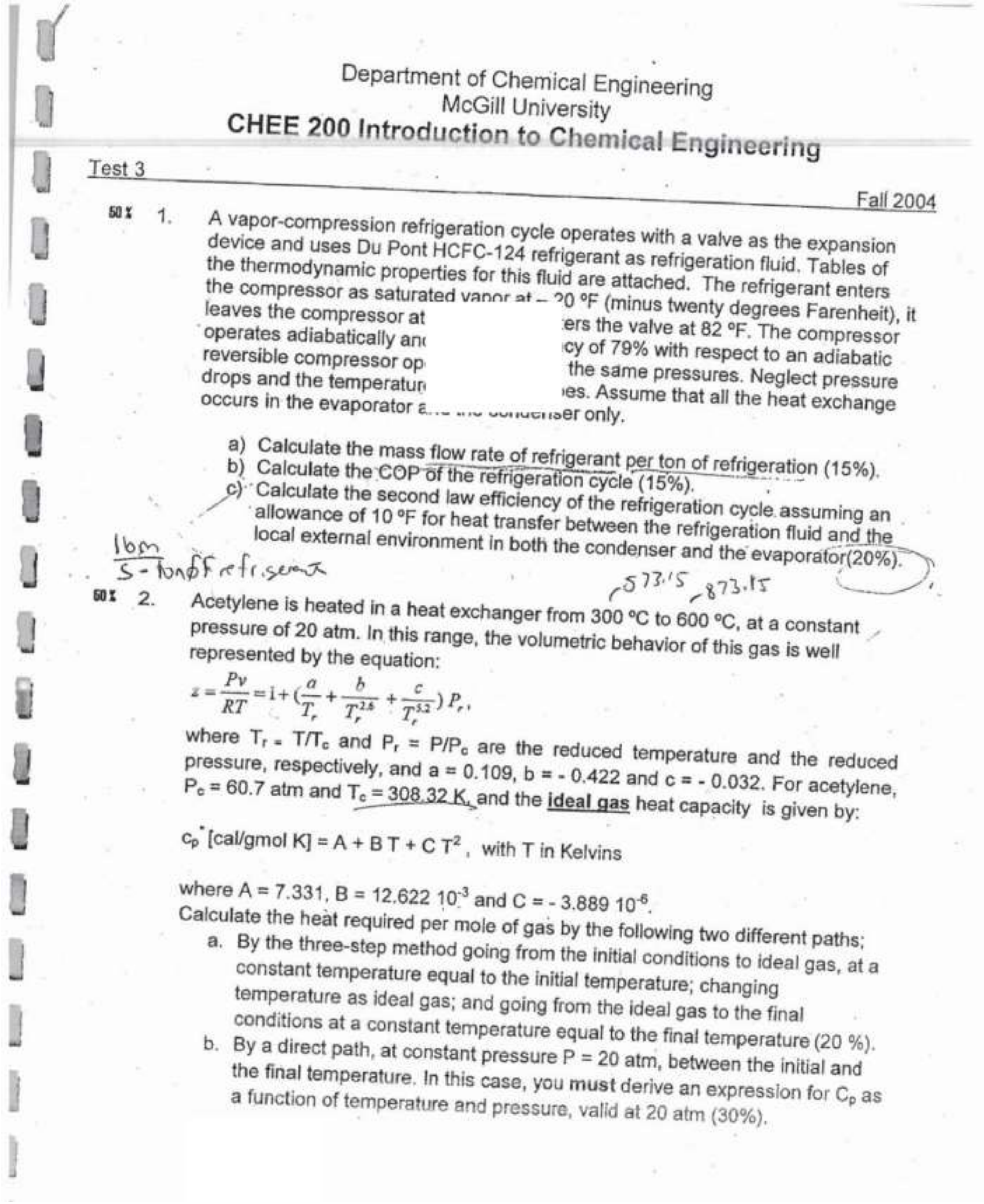
1. volume of a liquid is a weak function of pressure

2. for system 1, we have $Q - \int P dv = \Delta u$
for system 2, we have $Q = \Delta u$

$$\therefore \Delta u_1 < \Delta u_2$$
$$T_{Final,1} < T_{Final,2}$$

3. $\dot{w} = 384.8 \frac{kJ}{kg}$

Test 3



Department of Chemical Engineering
McGill University

CHEE 200 Introduction to Chemical Engineering

Test 3

Fall 2004

50 % 1. A vapor-compression refrigeration cycle operates with a valve as the expansion device and uses Du Pont HCFC-124 refrigerant as refrigeration fluid. Tables of the thermodynamic properties for this fluid are attached. The refrigerant enters the compressor as saturated vapor at – 20 °F (minus twenty degrees Farenheit), it leaves the compressor at [redacted] ers the valve at 82 °F. The compressor operates adiabatically an cy of 79% with respect to an adiabatic reversible compressor op the same pressures. Neglect pressure drops and the temperatur es. Assume that all the heat exchange occurs in the evaporator a ser only.

a) Calculate the mass flow rate of refrigerant per ton of refrigeration (15%).
b) Calculate the COP of the refrigeration cycle (15%).
c) Calculate the second law efficiency of the refrigeration cycle assuming an allowance of 10 °F for heat transfer between the refrigeration fluid and the local external environment in both the condenser and the evaporator(20%).

$\frac{lbm}{S - ton of refrigerant}$

573.15 873.15

50 % 2. Acetylene is heated in a heat exchanger from 300 °C to 600 °C, at a constant pressure of 20 atm. In this range, the volumetric behavior of this gas is well represented by the equation:

$$z = \frac{Pv}{RT} = 1 + \left(\frac{a}{T_r} + \frac{b}{T_r^{2.8}} + \frac{c}{T_r^{5.2}}\right) P_r ,$$

where $T_r = T/T_c$ and $P_r = P/P_c$ are the reduced temperature and the reduced pressure, respectively, and a = 0.109, b = - 0.422 and c = - 0.032. For acetylene, P_c = 60.7 atm and T_c = 308.32 K, and the **ideal gas** heat capacity is given by:

c_p^* [cal/gmol K] = A + B T + C T^2 , with T in Kelvins

where A = 7.331, B = 12.622 10^{-3} and C = - 3.889 10^{-6}.
Calculate the heat required per mole of gas by the following two different paths;

a. By the three-step method going from the initial conditions to ideal gas, at a constant temperature equal to the initial temperature; changing temperature as ideal gas; and going from the ideal gas to the final conditions at a constant temperature equal to the final temperature (20 %).
b. By a direct path, at constant pressure P = 20 atm, between the initial and the final temperature. In this case, you **must** derive an expression for C_p as a function of temperature and pressure, valid at 20 atm (30%).

Thermodynamic Properties of HCFC-124 Refrigerant (2-chloro-1,1,1,2-tetrafluoroethane)

Engineering (I/P) Units

New tables of the thermodynamic properties of HCFC-124 have been developed and are presented here. These tables are based on experimental data from the database at the National Institute of Standards and Technology (NIST). Equations have been developed, based on the Modified Benedict-Webb-Rubin (MBWR) equation of state, which represent the data with accuracy and consistency throughout the entire range of temperature, pressure, and density.

Physical Properties

Chemical Formula	$CHClFCF_3$	
Molecular Weight	136.48	
Boiling Point at One Atmosphere	10.25°F	(–12.09°C)
Critical Temperature	252.45°F 712.12°R	(122.47°C) (395.62 K)
Critical Pressure	527.1 psia	(3634.0 kPa [abs])
Critical Density	34.57 lb/ft^3	(553.8 kg/m^3)
Critical Volume	0.029 ft^3/lb	(0.00181 m^3/kg)

Units and Factors

t = temperature in °F
T = temperature in °R = °F + 459.67
P = pressure in lb/in^2 absolute (psia)
v_f = volume of saturated liquid in ft^3/lb
v_g = volume of saturated vapor in ft^3/lb
$\breve{V}$ = volume of superheated vapor in ft^3/lb
$d_f = 1/v_f$ = density of saturated liquid in lb/ft^3
$d_g = 1/v_g$ = density of saturated vapor in lb/ft^3
h_f = enthalpy of saturated liquid in Btu/lb
h_{fg} = enthalpy of vaporization in Btu/lb
h_g = enthalpy of saturated vapor in Btu/lb
$\breve{H}$ = enthalpy of superheated vapor in Btu/lb
s_f = entropy of saturated liquid in Btu/(lb) (°R)
s_g = entropy of saturated vapor in Btu/(lb) (°R)
$\breve{S}$ = entropy of superheated vapor in Btu/(lb) (°R)
C_p = heat capacity at constant pressure in Btu/(lb) (°F)
C_v = heat capacity at constant volume in Btu/(lb) (°F)
v_s = velocity of sound in ft/sec

The gas constant, $R = 10.732$ (psia) $(ft^3)/(°R)$ (lb–mole)
for HCFC-124, $R = 0.0786$ (psia) $(ft^3)/lb \cdot °R$
One atmosphere = 14.696 psia
Conversion factor from Work Units to Heat Units:
$J = 0.185053$
$Btu/lb = (psia \cdot ft^3)/lb \cdot J$
Reference point for enthalpy and entropy:
$h_f = 0.0$ Btu/lb at –40°F
$s_f = 0.0$ Btu/lb · °R at –40°F

Equations

The Modified Benedict-Webb-Rubin (MBWR) equation of state was used to calculate the tables of thermodynamic properties. It was chosen as the preferred equation of state because it provided the most accurate fit of the thermodynamic data over the entire range of temperatures and pressures presented in these tables. The data fit and calculation of constants for HCFC-124 were performed for Du Pont at the National Institute of Standards and Technology (NIST) under the supervision of Dr. Mark O. McLinden.

The constants were calculated in SI units. For conversion of thermodynamic properties to Engineering (I/P) units, properties must be calculated in SI units and converted to I/P units. Conversion factors are provided for each property derived from the MBWR equation of state.

1. **Equation of State (MBWR)**

$$P = \sum_{n=1}^{9} a_n/V^n + \exp(-V_c^2/V^2) \sum_{n=10}^{15} a_n/V^{2n-17}$$

where the temperature dependence of the coefficients is given by:

$$
\begin{aligned}
a_1 &= RT \\
a_2 &= b_1 T + b_2 T^{0.5} + b_3 + b_4/T + b_5/T^2 \\
a_3 &= b_6 T + b_7 + b_8/T + b_9/T^2 \\
a_4 &= b_{10} T + b_{11} + b_{12}/T \\
a_5 &= b_{13} \\
a_6 &= b_{14}/T + b_{15}/T^2 \\
a_7 &= b_{16}/T \\
a_8 &= b_{17}/T + b_{18}/T^2 \\
a_9 &= b_{19}/T^2 \\
a_{10} &= b_{20}/T^2 + b_{21}/T^3 \\
a_{11} &= b_{22}/T^2 + b_{23}/T^4 \\
a_{12} &= b_{24}/T^2 + b_{25}/T^3 \\
a_{13} &= b_{26}/T^2 + b_{27}/T^4 \\
a_{14} &= b_{28}/T^2 + b_{29}/T^3 \\
a_{15} &= b_{30}/T^2 + b_{31}/T^3 + b_{32}/T^4
\end{aligned}
$$

where T is in K = °C + 273.15, V is in m^3/mole, P is in kPa, and $R = 8.314471$ J/(mole) (K)

TABLE 1 (continued)
HCFC–124 Saturation Properties—Temperature Table

TEMP.	PRESSURE	VOLUME ft³/lb		DENSITY lb/ft³		ENTHALPY Btu/lb			ENTROPY Btu/(lb)(°R)		TEMP.
°F	psia	LIQUID v_f	VAPOR v_g	LIQUID $1/v_f$	VAPOR $1/v_g$	LIQUID h_f	LATENT h_{fg}	VAPOR h_g	LIQUID s_f	VAPOR s_g	°F
−30	5.216	0.0104	6.2893	96.04	0.1590	2.5	74.6	77.0	0.0058	0.1793	−30
−29	5.367	0.0104	6.1237	95.94	0.1633	2.7	74.4	77.1	0.0063	0.1792	−29
−28	5.522	0.0104	5.9630	95.85	0.1677	2.9	74.3	77.3	0.0069	0.1791	−28
−27	5.680	0.0104	5.8106	95.75	0.1721	3.2	74.2	77.4	0.0075	0.1790	−27
−26	5.841	0.0105	5.6593	95.65	0.1767	3.4	74.1	77.5	0.0080	0.1789	−26
−25	6.006	0.0105	5.5127	95.55	0.1814	3.7	74.0	77.7	0.0086	0.1788	−25
−24	6.175	0.0105	5.3706	95.46	0.1862	3.9	73.9	77.8	0.0091	0.1788	−24
−23	6.348	0.0105	5.2329	95.36	0.1911	4.2	73.8	77.9	0.0097	0.1787	−23
−22	6.525	0.0105	5.1020	95.26	0.1960	4.4	73.7	78.1	0.0103	0.1786	−22
−21	6.705	0.0105	4.9727	95.16	0.2011	4.6	73.6	78.2	0.0108	0.1785	−21
−20	6.890	0.0105	4.8473	95.06	0.2063	4.9	73.5	78.3	0.0114	0.1785	−20
−19	7.078	0.0105	4.7259	94.97	0.2116	5.1	73.4	78.5	0.0119	0.1784	−19
−18	7.271	0.0105	4.6083	94.87	0.2170	5.4	73.2	78.6	0.0125	0.1783	−18
−17	7.468	0.0106	4.4944	94.77	0.2225	5.6	73.1	78.8	0.0130	0.1782	−17
−16	7.669	0.0106	4.3840	94.67	0.2281	5.9	73.0	78.9	0.0136	0.1782	−16
−15	7.874	0.0106	4.2772	94.57	0.2338	6.1	72.9	79.0	0.0141	0.1781	−15
−14	8.085	0.0106	4.1719	94.47	0.2397	6.3	72.8	79.2	0.0146	0.1780	−14
−13	8.299	0.0106	4.0717	94.37	0.2456	6.6	72.7	79.3	0.0152	0.1780	−13
−12	8.518	0.0106	3.9730	94.27	0.2517	6.8	72.6	79.4	0.0157	0.1779	−12
−11	8.741	0.0106	3.8775	94.17	0.2579	7.1	72.5	79.6	0.0163	0.1778	−11
−10	8.969	0.0106	3.7850	94.07	0.2642	7.3	72.4	79.7	0.0168	0.1778	−10
−9	9.202	0.0106	3.6955	93.97	0.2706	7.6	72.3	79.8	0.0174	0.1777	−9
−8	9.439	0.0107	3.6075	93.87	0.2772	7.8	72.2	80.0	0.0179	0.1777	−8
−7	9.682	0.0107	3.5224	93.77	0.2839	8.0	72.1	80.1	0.0184	0.1776	−7
−6	9.929	0.0107	3.4400	93.67	0.2907	8.3	71.9	80.2	0.0190	0.1775	−6
−5	10.181	0.0107	3.3602	93.57	0.2976	8.5	71.8	80.4	0.0195	0.1775	−5
−4	10.439	0.0107	3.2830	93.47	0.3046	8.8	71.7	80.5	0.0200	0.1774	−4
−3	10.701	0.0107	3.2072	93.37	0.3118	9.0	71.6	80.6	0.0206	0.1774	−3
−2	10.968	0.0107	3.1328	93.27	0.3192	9.3	71.5	80.8	0.0211	0.1773	−2
−1	11.241	0.0107	3.0618	93.17	0.3266	9.5	71.4	80.9	0.0216	0.1773	−1
0	11.520	0.0107	2.9922	93.07	0.3342	9.7	71.3	81.0	0.0222	0.1772	0
1	11.803	0.0108	2.9248	92.97	0.3419	10.0	71.2	81.2	0.0227	0.1772	1
2	12.092	0.0108	2.8588	92.86	0.3498	10.2	71.1	81.3	0.0232	0.1772	2
3	12.387	0.0108	2.7949	92.76	0.3578	10.5	71.0	81.4	0.0237	0.1771	3
4	12.687	0.0108	2.7322	92.66	0.3660	10.7	70.9	81.6	0.0243	0.1771	4
5	12.994	0.0108	2.6717	92.56	0.3743	11.0	70.7	81.7	0.0248	0.1770	5
6	13.305	0.0108	2.6130	92.46	0.3827	11.2	70.6	81.8	0.0253	0.1770	6
7	13.623	0.0108	2.5556	92.35	0.3913	11.5	70.5	82.0	0.0258	0.1770	7
8	13.947	0.0108	2.4994	92.25	0.4001	11.7	70.4	82.1	0.0263	0.1769	8
9	14.277	0.0109	2.4450	92.15	0.4090	11.9	70.3	82.2	0.0269	0.1769	9
10	14.613	0.0109	2.3918	92.04	0.4181	12.2	70.2	82.4	0.0274	0.1768	10
11	14.955	0.0109	2.3403	91.94	0.4273	12.4	70.1	82.5	0.0279	0.1768	11
12	15.303	0.0109	2.2904	91.84	0.4366	12.7	70.0	82.6	0.0284	0.1768	12
13	15.658	0.0109	2.2411	91.73	0.4462	12.9	69.9	82.8	0.0289	0.1767	13
14	16.019	0.0109	2.1935	91.63	0.4559	13.2	69.6	82.9	0.0295	0.1767	14
15	16.386	0.0109	2.1473	91.53	0.4657	13.4	69.6	83.0	0.0300	0.1767	15
16	16.761	0.0109	2.1017	91.42	0.4758	13.7	69.5	83.2	0.0305	0.1767	16
17	17.141	0.0110	2.0576	91.32	0.4860	13.9	69.4	83.3	0.0310	0.1766	17
18	17.529	0.0110	2.0149	91.21	0.4963	14.1	69.3	83.5	0.0315	0.1766	18
19	17.923	0.0110	1.9728	91.11	0.5069	14.4	69.2	83.6	0.0320	0.1766	19
20	18.325	0.0110	1.9320	91.00	0.5176	14.6	69.1	83.7	0.0325	0.1766	20
21	18.733	0.0110	1.8921	90.90	0.5285	14.9	69.0	83.9	0.0331	0.1765	21
22	19.149	0.0110	1.8532	90.79	0.5396	15.1	68.9	84.0	0.0336	0.1765	22
23	19.571	0.0110	1.8155	90.69	0.5508	15.4	68.7	84.1	0.0341	0.1765	23
24	20.001	0.0110	1.7787	90.58	0.5622	15.6	69.6	84.3	0.0346	0.1765	24
25	20.438	0.0111	1.7425	90.48	0.5739	15.9	68.5	84.4	0.0351	0.1765	25
26	20.883	0.0111	1.7074	90.37	0.5857	16.1	68.4	84.5	0.0356	0.1764	26
27	21.335	0.0111	1.6731	90.26	0.5977	16.4	68.3	84.7	0.0361	0.1764	27
28	21.795	0.0111	1.6398	90.16	0.6099	16.6	68.2	84.8	0.0366	0.1764	28
29	22.262	0.0111	1.6072	90.05	0.6222	16.9	68.1	84.9	0.0371	0.1764	29

TABLE 1 (continued)

HCFC–124 Saturation Properties—Temperature Table

TEMP. °F	PRESSURE psia	VOLUME ft³/lb LIQUID v_f	VOLUME ft³/lb VAPOR v_g	DENSITY lb/ft³ LIQUID $1/v_f$	DENSITY lb/ft³ VAPOR $1/v_g$	ENTHALPY Btu/lb LIQUID h_f	ENTHALPY Btu/lb LATENT h_{fg}	ENTHALPY Btu/lb VAPOR h_g	ENTROPY Btu/(lb)(°R) LIQUID s_f	ENTROPY Btu/(lb)(°R) VAPOR s_g	TEMP. °F
30	22.737	0.0111	1.5753	89.94	0.6348	17.1	67.9	85.1	0.0376	0.1764	30
31	23.220	0.0111	1.5442	89.84	0.6476	17.4	67.8	85.2	0.0381	0.1764	31
32	23.711	0.0111	1.5138	89.73	0.6606	17.8	67.7	85.3	0.0386	0.1764	32
33	24.210	0.0112	1.4841	89.62	0.6738	17.9	67.6	85.5	0.0391	0.1763	33
34	24.717	0.0112	1.4552	89.51	0.6872	18.1	67.5	85.6	0.0396	0.1763	34
35	25.233	0.0112	1.4269	89.41	0.7008	18.4	67.4	85.7	0.0401	0.1763	35
36	25.756	0.0112	1.3994	89.30	0.7146	18.6	67.2	85.9	0.0406	0.1763	36
37	26.288	0.0112	1.3725	89.19	0.7286	18.9	67.1	86.0	0.0411	0.1763	37
38	26.829	0.0112	1.3463	89.08	0.7428	19.1	67.0	86.1	0.0417	0.1763	38
39	27.378	0.0112	1.3205	88.97	0.7573	19.4	66.9	86.3	0.0422	0.1763	39
40	27.935	0.0113	1.2955	88.86	0.7719	19.6	66.8	86.4	0.0427	0.1763	40
41	28.502	0.0113	1.2710	88.75	0.7868	19.9	66.7	86.5	0.0432	0.1763	41
42	29.077	0.0113	1.2469	88.64	0.8020	20.1	66.5	86.7	0.0437	0.1763	42
43	29.661	0.0113	1.2235	88.53	0.8173	20.4	66.4	86.8	0.0442	0.1763	43
44	30.254	0.0113	1.2006	88.42	0.8329	20.6	66.3	86.9	0.0446	0.1763	44
45	30.857	0.0113	1.1783	88.31	0.8487	20.9	66.2	87.1	0.0451	0.1763	45
46	31.468	0.0113	1.1565	88.20	0.8647	21.1	66.1	87.2	0.0456	0.1763	46
47	32.089	0.0114	1.1351	88.09	0.8810	21.4	65.9	87.3	0.0461	0.1763	47
48	32.719	0.0114	1.1142	87.98	0.8975	21.6	65.8	87.4	0.0466	0.1763	48
49	33.359	0.0114	1.0937	87.87	0.9143	21.9	65.7	87.5	0.0471	0.1763	49
50	34.008	0.0114	1.0738	87.76	0.9313	22.1	65.6	87.7	0.0476	0.1763	50
51	34.667	0.0114	1.0542	87.65	0.9486	22.4	65.5	87.8	0.0481	0.1763	51
52	35.336	0.0114	1.0351	87.54	0.9661	22.6	65.3	88.0	0.0486	0.1763	52
53	36.014	0.0114	1.0164	87.42	0.9839	22.9	65.2	88.1	0.0491	0.1763	53
54	36.703	0.0115	0.9981	87.31	1.0019	23.2	65.1	88.2	0.0496	0.1763	54
55	37.401	0.0115	0.9802	87.20	1.0202	23.4	65.0	88.4	0.0501	0.1763	55
56	38.110	0.0115	0.9627	87.09	1.0387	23.7	64.8	88.5	0.0506	0.1763	56
57	38.829	0.0115	0.9456	86.97	1.0575	23.9	64.7	88.6	0.0511	0.1764	57
58	39.559	0.0115	0.9289	86.86	1.0766	24.2	64.6	88.8	0.0516	0.1764	58
59	40.298	0.0115	0.9125	86.74	1.0959	24.4	64.5	88.9	0.0521	0.1764	59
60	41.049	0.0115	0.8964	86.63	1.1156	24.7	64.3	89.0	0.0526	0.1764	60
61	41.810	0.0116	0.8807	86.52	1.1354	24.9	64.2	89.2	0.0531	0.1764	61
62	42.581	0.0116	0.8654	86.40	1.1556	25.2	64.1	89.3	0.0536	0.1764	62
63	43.364	0.0116	0.8503	86.29	1.1761	25.5	64.0	89.4	0.0540	0.1764	63
64	44.157	0.0116	0.8356	86.17	1.1968	25.7	63.8	89.6	0.0545	0.1764	64
65	44.962	0.0116	0.8211	86.06	1.2179	26.0	63.7	89.7	0.0550	0.1765	65
66	45.778	0.0116	0.8070	85.94	1.2392	26.2	63.6	89.8	0.0555	0.1765	66
67	46.604	0.0117	0.7931	85.83	1.2608	26.5	63.5	90.0	0.0560	0.1765	67
68	47.443	0.0117	0.7796	85.71	1.2827	26.8	63.3	90.1	0.0565	0.1765	68
69	48.292	0.0117	0.7663	85.59	1.3049	27.0	63.2	90.2	0.0570	0.1765	69
70	49.153	0.0117	0.7533	85.48	1.3275	27.3	63.1	90.3	0.0575	0.1765	70
71	50.026	0.0117	0.7406	85.36	1.3503	27.5	62.9	90.5	0.0580	0.1766	71
72	50.911	0.0117	0.7281	85.24	1.3735	27.8	62.8	90.6	0.0585	0.1766	72
73	51.807	0.0117	0.7159	85.12	1.3969	28.1	62.7	90.7	0.0589	0.1766	73
74	52.716	0.0118	0.7039	85.01	1.4207	28.3	62.5	90.9	0.0594	0.1766	74
75	53.636	0.0118	0.6921	84.89	1.4448	28.6	62.4	91.0	0.0599	0.1766	75
76	54.568	0.0118	0.6806	84.77	1.4692	28.9	62.3	91.1	0.0604	0.1767	76
77	55.513	0.0118	0.6693	84.65	1.4940	29.1	62.1	91.3	0.0609	0.1767	77
78	56.470	0.0118	0.6583	84.53	1.5191	29.4	62.0	91.4	0.0614	0.1767	78
79	57.440	0.0118	0.6475	84.41	1.5445	29.6	61.9	91.5	0.0619	0.1767	79
80	58.422	0.0119	0.6368	84.29	1.5703	29.9	61.7	91.6	0.0624	0.1768	80
81	59.417	0.0119	0.6264	84.17	1.5964	30.2	61.6	91.8	0.0628	0.1768	81
82	60.425	0.0119	0.6162	84.05	1.6228	30.4	61.5	91.9	0.0633	0.1768	82
83	61.445	0.0119	0.6062	83.93	1.6496	30.7	61.3	92.0	0.0638	0.1768	83
84	62.478	0.0119	0.5964	83.81	1.6768	31.0	61.2	92.2	0.0643	0.1769	84
85	63.525	0.0119	0.5866	83.69	1.7043	31.2	61.1	92.3	0.0648	0.1769	85
86	64.585	0.0120	0.5773	83.56	1.7322	31.5	60.9	92.4	0.0653	0.1769	86
87	65.658	0.0120	0.5680	83.44	1.7605	31.8	60.8	92.6	0.0658	0.1769	87
88	66.744	0.0120	0.5589	83.32	1.7891	32.0	60.6	92.7	0.0662	0.1770	88
89	67.844	0.0120	0.5500	83.19	1.8181	32.3	60.5	92.8	0.0667	0.1770	89

TABLE 2 (continued)

HCFC-124 Superheated Vapor—Constant Pressure Tables

V = Volume in ft³/lb H = Enthalpy in Btu/lb S = Entropy in Btu/(lb) (°R) v_s = Velocity of Sound in ft/sec
Cp = Heat Capacity at Constant Pressure in Btu/(lb) (°F) Cp/Cv = Heat Capacity Ratio (Dimensionless)

TEMP °F	PRESSURE = 60.00 PSIA V	H	S	Cp	Cp/Cv	v_s
81.58	0.0119	30.3	0.0631	0.2652	1.4968	1685.4
81.58	0.6205	91.9	0.1768	0.2106	1.1768	417.5
90	0.6366	93.6	0.1800	0.2081	1.1657	423.7
100	0.6551	95.7	0.1838	0.2058	1.1548	430.7
110	0.6729	97.7	0.1874	0.2042	1.1456	437.3
120	0.6903	99.8	0.1909	0.2031	1.1379	443.6
130	0.7072	101.8	0.1944	0.2025	1.1313	449.6
140	0.7237	103.8	0.1978	0.2021	1.1257	455.3
150	0.7399	105.8	0.2011	0.2020	1.1207	460.9
160	0.7558	107.9	0.2044	0.2022	1.1164	466.3
170	0.7715	109.9	0.2077	0.2026	1.1126	471.5
180	0.7870	111.9	0.2109	0.2031	1.1092	476.6
190	0.8022	113.9	0.2140	0.2038	1.1062	481.5
200	0.8175	116.0	0.2171	0.2046	1.1034	486.4
210	0.8324	118.0	0.2202	0.2055	1.1009	491.1
220	0.8473	120.1	0.2233	0.2065	1.0987	495.7
230	0.8620	122.2	0.2263	0.2075	1.0966	500.3
240	0.8767	124.3	0.2293	0.2087	1.0948	504.7
250	0.8912	126.3	0.2323	0.2099	1.0930	509.1
260	0.9057	128.4	0.2352	0.2111	1.0914	513.4
270	0.9202	130.6	0.2381	0.2124	1.0899	517.7
280	0.9345	132.7	0.2410	0.2137	1.0885	521.9
290	0.9487	134.8	0.2439	0.2151	1.0872	526.0
300	0.9629	137.0	0.2468	0.2165	1.0860	530.1
310	0.9772	139.2	0.2496	0.2179	1.0848	534.2
320	0.9914	141.4	0.2524	0.2193	1.0837	538.2
330	1.0056	143.6	0.2552	0.2208	1.0827	542.1
340	1.0197	145.8	0.2580	0.2222	1.0817	546.0
350	1.0338	148.0	0.2608	0.2237	1.0807	549.9
360	1.0477	150.2	0.2635	0.2252	1.0798	553.7
370	1.0616	152.5	0.2663	0.2267	1.0790	557.5
380	1.0758	154.8	0.2690	0.2281	1.0781	561.3
390	1.0897	157.1	0.2717	0.2295	1.0773	565.0

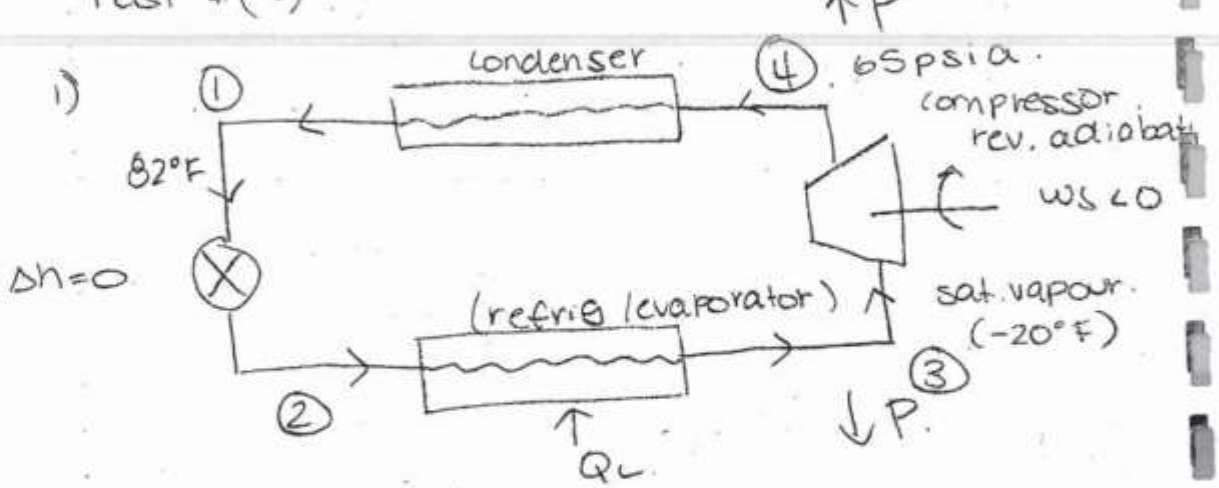
	PRESSURE = 65.00 PSIA V	H	S	Cp	Cp/Cv	v_s	TEMP °F
SAT LIQ	0.0120	31.6	0.0655	0.2672	1.4997	1651.6	85.39
SAT VAP	0.5737	92.5	0.1769	0.2132	1.1809	416.6	85.39
	0.5802	93.2	0.1783	0.2120	1.1756	419.4	90
	0.5979	95.3	0.1821	0.2091	1.1630	426.7	100
	0.6148	97.4	0.1858	0.2070	1.1526	433.7	110
	0.6313	99.5	0.1894	0.2056	1.1438	440.2	120
	0.6473	101.5	0.1929	0.2045	1.1364	446.4	130
	0.6629	103.6	0.1963	0.2039	1.1301	452.4	140
	0.6781	105.6	0.1997	0.2036	1.1246	458.2	150
	0.6931	107.7	0.2030	0.2036	1.1199	463.7	160
	0.7078	109.7	0.2063	0.2038	1.1157	469.1	170
	0.7224	111.7	0.2095	0.2042	1.1120	474.3	180
	0.7367	113.8	0.2127	0.2048	1.1087	479.4	190
	0.7508	115.8	0.2158	0.2055	1.1057	484.3	200
	0.7647	117.9	0.2189	0.2063	1.1030	489.1	210
	0.7787	120.0	0.2220	0.2072	1.1006	493.9	220
	0.7924	122.0	0.2250	0.2082	1.0984	498.5	230
	0.8061	124.1	0.2280	0.2093	1.0964	503.1	240
	0.8197	126.2	0.2310	0.2104	1.0946	507.5	250
	0.8330	128.3	0.2339	0.2116	1.0928	511.9	260
	0.8465	130.4	0.2368	0.2128	1.0913	516.2	270
	0.8598	132.6	0.2398	0.2141	1.0898	520.5	280
	0.8731	134.7	0.2426	0.2154	1.0884	524.7	290
	0.8864	136.9	0.2455	0.2168	1.0871	528.9	300
	0.8996	139.1	0.2483	0.2182	1.0859	533.0	310
	0.9127	141.3	0.2512	0.2196	1.0847	537.0	320
	0.9258	143.5	0.2540	0.2210	1.0837	541.0	330
	0.9388	145.7	0.2568	0.2225	1.0826	545.0	340
	0.9521	147.9	0.2595	0.2239	1.0816	548.9	350
	0.9650	150.2	0.2623	0.2254	1.0807	552.8	360
	0.9781	152.4	0.2650	0.2268	1.0798	556.6	370
	0.9910	154.7	0.2678	0.2283	1.0790	560.4	380
	1.0040	157.0	0.2705	0.2298	1.0781	564.2	390

TEMP °F	PRESSURE = 70.00 PSIA V	H	S	Cp	Cp/Cv	v_s
90.93	0.0121	32.8	0.0677	0.2692	1.5025	1619.5
90.93	0.5333	93.1	0.1770	0.2157	1.1850	415.7
100	0.5487	95.0	0.1805	0.2126	1.1719	422.7
110	0.5649	97.1	0.1843	0.2100	1.1600	429.9
120	0.5806	99.2	0.1879	0.2081	1.1501	436.8
130	0.5958	101.3	0.1915	0.2067	1.1418	443.3
140	0.6106	103.3	0.1949	0.2058	1.1348	449.5
150	0.6251	105.4	0.1983	0.2053	1.1287	455.4
160	0.6392	107.4	0.2017	0.2051	1.1235	461.1
170	0.6532	109.5	0.2050	0.2051	1.1189	466.6
180	0.6668	111.5	0.2082	0.2053	1.1149	472.0
190	0.6802	113.6	0.2114	0.2058	1.1113	477.2
200	0.6936	115.7	0.2145	0.2064	1.1081	482.2
210	0.7068	117.7	0.2176	0.2071	1.1052	487.2
220	0.7198	119.8	0.2207	0.2079	1.1026	492.0
230	0.7327	121.9	0.2238	0.2088	1.1002	496.7
240	0.7454	124.0	0.2268	0.2098	1.0981	501.4
250	0.7582	126.1	0.2298	0.2109	1.0961	505.9
260	0.7709	128.2	0.2327	0.2121	1.0943	510.4
270	0.7834	130.3	0.2356	0.2133	1.0926	514.8
280	0.7959	132.5	0.2386	0.2145	1.0911	519.1
290	0.8083	134.6	0.2414	0.2158	1.0896	523.4
300	0.8208	136.8	0.2443	0.2171	1.0883	527.6
310	0.8330	139.0	0.2472	0.2185	1.0870	531.7
320	0.8453	141.1	0.2500	0.2199	1.0858	535.8
330	0.8575	143.4	0.2528	0.2213	1.0847	539.9
340	0.8698	145.6	0.2556	0.2227	1.0836	543.9
350	0.8821	147.8	0.2584	0.2241	1.0826	547.9
360	0.8941	150.1	0.2611	0.2256	1.0815	551.8
370	0.9063	152.3	0.2639	0.2270	1.0807	555.7
380	0.9184	154.6	0.2666	0.2285	1.0798	559.5
390	0.9306	156.9	0.2693	0.2300	1.0789	563.3
400	0.9426	159.2	0.2720	0.2314	1.0781	567.1

	PRESSURE = 75.00 PSIA V	H	S	Cp	Cp/Cv	v_s	TEMP °F
SAT LIQ	0.0121	34.0	0.0698	0.2711	1.5054	1588.8	95.23
SAT VAP	0.4982	93.6	0.1772	0.2182	1.1891	414.7	95.23
	0.5059	94.6	0.1790	0.2163	1.1816	418.5	100
	0.5216	96.8	0.1828	0.2131	1.1680	426.1	110
	0.5366	98.9	0.1865	0.2107	1.1568	433.3	120
	0.5512	101.0	0.1901	0.2090	1.1476	440.0	130
	0.5653	103.1	0.1936	0.2078	1.1397	446.5	140
	0.5791	105.2	0.1970	0.2070	1.1330	452.6	150
	0.5925	107.2	0.2004	0.2066	1.1273	458.5	160
	0.6057	109.3	0.2037	0.2064	1.1222	464.2	170
	0.6187	111.4	0.2070	0.2065	1.1178	469.7	180
	0.6314	113.4	0.2102	0.2068	1.1140	475.0	190
	0.6440	115.5	0.2133	0.2073	1.1105	480.2	200
	0.6565	117.6	0.2165	0.2079	1.1074	485.2	210
	0.6688	119.7	0.2195	0.2086	1.1046	490.1	220
	0.6809	121.7	0.2226	0.2095	1.1021	495.0	230
	0.6930	123.8	0.2256	0.2104	1.0998	499.7	240
	0.7049	126.0	0.2286	0.2115	1.0977	504.3	250
	0.7169	128.1	0.2316	0.2126	1.0958	508.9	260
	0.7286	130.2	0.2345	0.2137	1.0941	513.3	270
	0.7404	132.3	0.2374	0.2149	1.0924	517.7	280
	0.7522	134.5	0.2403	0.2162	1.0909	522.0	290
	0.7637	136.7	0.2432	0.2175	1.0895	526.3	300
	0.7754	138.9	0.2461	0.2188	1.0881	530.5	310
	0.7869	141.0	0.2489	0.2201	1.0869	534.7	320
	0.7985	143.3	0.2517	0.2215	1.0857	538.8	330
	0.8099	145.5	0.2545	0.2229	1.0846	542.6	340
	0.8213	147.7	0.2573	0.2243	1.0835	546.9	350
	0.8328	150.0	0.2600	0.2258	1.0825	550.8	360
	0.8441	152.2	0.2628	0.2272	1.0816	554.7	370
	0.8558	154.5	0.2655	0.2287	1.0806	558.6	380
	0.8669	156.9	0.2682	0.2301	1.0798	562.5	390
	0.8782	159.1	0.2709	0.2316	1.0789	566.3	400

TEST #(3)

1)



a) going through the refrigerator,
open flow system: $\Delta H + \cancel{\Delta E_k}^{0} + \cancel{\Delta E_p}^{0} = Q - \cancel{W_s}^{0}$

$\Delta h = q \rightarrow \Delta H = Q$

(h_2) $\Delta h = 0$ for a valve $\therefore h_1 = h_2$

↳ (82°F, 65 psia) → below saturation → liquid

↳ $h_2 = 30.4$ BTU/lb.

h_3(sat, vapour, -20°F) = 78.3 BTU/lb.

$h_3 - h_2 = q \qquad 78.3 - 30.4 = 47.9$ BTU/lb

mass flow rate = $x \frac{lb}{hr}$ $\qquad 47.9 \frac{BTU}{lb} \times x \frac{lb}{hr} = 12000 \frac{BTU}{hr}$

$$\boxed{x = 250.52 \frac{lb}{hr}}$$

b) $COP = \frac{Q_L}{-W_{actual}} = \frac{47.9 \frac{BTU}{lb}}{-W_{actual}}$

wactual → compressor: Ws (adiabatic revs)

$h_3 = 78.3$ BTU/lb

$S_3 = 0.1785 \frac{BTU}{lb°R} = S_4$

(65psia, 0.1785) = 93.2 $\frac{BTU}{lb}$

$h_4 - h_3 = -W_s$

$93.2 - 78.3 = 14.9 \frac{\text{BTU}}{\text{lb}} = W_s$ reversible.

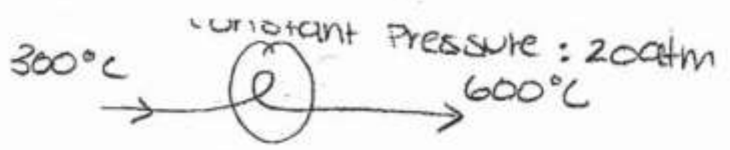
$0.79 = \frac{-W_s\ \text{rev}}{-W_s\ \text{act}}$ $\quad \frac{14.9}{0.79} = -W_s$ actual $= 18.86$.

$\frac{47.9}{18.86} = 2.539$

2nd law efficiency. $\eta = \frac{Q_L(T_H - T_L)}{-WT_L} = \underline{47.9(82+459.69-}$

$= \frac{47.9}{18.86} \frac{(72+459.69-449.69)}{449.69} = 0.46.$

②,



Part b

$$\left(\frac{\partial C_P}{\partial P}\right)_T = -T\left(\frac{\partial^2 V}{\partial T^2}\right)_P \qquad \frac{PV}{RT} = 1 + \left(\frac{a}{T_r} + \frac{b}{T_r^{2.6}} + \frac{c}{T_r^{5.2}}\right) P_r$$

$$\frac{PV}{RT} = 1 + \left(\frac{aT_c}{T} + b\frac{T_c^{2.6}}{T^{2.6}} + \frac{cT_c^{5.2}}{T^{5.2}}\right)\frac{P}{P_c}$$

$$V = \frac{RT}{P} + \left(\frac{aT_c}{T} + \frac{bT_c^{2.6}}{T^{2.6}} + \frac{cT_c^{5.2}}{T^{5.2}}\right)\frac{RT}{P_c}$$

$$V = \frac{RT}{P} + \frac{aRT_c}{P_c} + \frac{bRT_c^{2.6}}{P_c T^{1.6}} + \frac{cRT_c^{5.2}}{P_c T^{4.2}}$$

$$\left(\frac{\partial V}{\partial T}\right)_P = \frac{R}{P} + (-1.6)\frac{bRT_c^{2.6}}{P_c T^{2.6}} + (-4.2)\frac{cRT_c^{5.2}}{P_c T^{5.2}}$$

$$\left(\frac{\partial^2 V}{\partial T^2}\right)_P = (-1.6)(-2.6)\frac{bRT_c^{2.6}}{P_c T^{3.6}} + (-4.2)(-5.2)\frac{cRT_c^{5.2}}{P_c T^{6.2}}$$

$$-T\left(\frac{\partial^2 V}{\partial T^2}\right)_P = -(1.6)(2.6)\frac{bRT_c^{2.6}}{P_c T^{2.6}} - (4.2)(5.2)\frac{cRT_c^{5.2}}{P_c T^{5.2}}$$

$$= -\frac{(1.6)(2.6)(-0.422)(308.32k)^{2.6} R}{(60.7atm)\, T^{2.6}}$$

$$-\frac{(4.2)(5.2)(-0.032)(308.32k)^{5.2} R}{(60.7atm)\, T^{5.2}}$$

$$= 85\,629.12447 \frac{k}{atm}\frac{R}{T^{2.6}} + 1.00930575\times10^{11} \frac{k}{atm}\frac{R}{T^{5.2}}$$

$$Cp(20atm) = Cp^* + \int_0^{20atm}\left(-T\left(\frac{\partial^2 V}{\partial T}\right)_P\right) dP.$$

$$= 7.331 + 12.622\times10^{-3}T - 3.889\times10^{-6}T^2 + \left[85629.12447\frac{R}{T^{2.6}}P + 1.00930575\times10^{11}\frac{R}{T^{5.2}}P\right]\Bigg|_0^{20\,atm}$$

$$= 7.331 + 12.622\times10^{-3}T - 3.889\times10^{-6}T^2 + \left(85629.12\frac{R}{T^{2.6}} + 100930575\times10^{11}\frac{R}{T^{5.2}}\right)(20atm - 0)$$

$$\boxed{* R = 1.987 \frac{cal}{g\text{-}mol\,k}}$$

$$p(20) = 7.331 + 12.622\times10^{-3}T - 3.889\times10^{-6}T^2 + 3402\,901.406\,T^{-2.6} + 4.010981049\times10^{12}\,T^{-5.2}$$

$T_1 = 300°C = 573.16k$

$T_2 = 600°C = 873.16k$

$$\Delta h = \int_{T_1}^{T_2} Cp\,(20atm)$$

$$= \int_{573.16}^{873.16} 7.331 + 12.622\times10^{-3}\,T - 3.889\times10^{-6}T^2 + 3402\,901.406\,T^{-2.6} + 4.010981049\times10^{12}\,T^{-5.2}$$

$$= 4318.729524\frac{cal}{gmol} + 42.311\frac{cal}{gmol}$$

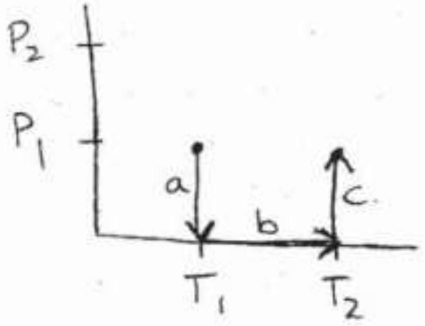
$$\boxed{= 4\,361.040524 \ \frac{cal}{gmol}}$$

∴ the heat required per mole of gas is 4.36×10^{3} ca

Part A

$$\Delta h = \int_{T_1}^{T_2} Cp^* \, dT + \lim_{p^*\to 0}\int_{P_1}^{p^*} V - T\left(\frac{\partial V}{\partial T}\right)_p dP$$

$$+ \int_{P^*}^{P_2} V - T\left(\frac{\partial V}{\partial T}\right)_p dP$$



$$\int_{T_1}^{T_2} cp^* \, dT = \int_{573.16}^{873.16} 7.331 + 12.622\times10^{-3}T - 3.889\times10^{-6}T^2$$

$$= 4318.729524 \ \frac{cal}{g\text{-}mol}$$

$$-T\left(\frac{\partial V}{\partial P}\right)_p = -\frac{TR}{P} + \frac{1.6bRT_c^{2.6}}{P_cT^{1.6}} + \frac{4.2cRT_c^{5.2}}{P_cT^{4.2}}$$

$$V - T\left(\frac{\partial V}{\partial P}\right)_p = \frac{\cancel{RT}}{\cancel{P}} + \frac{aRTc}{P_c} + \frac{bRT_c^{2.6}}{P_cT^{1.6}} + \frac{cRT_c^{5.2}}{P_cT^{4.2}} - \frac{T\cancel{R}}{\cancel{P}} + \frac{1.6\,bRT_c^{2.6}}{P_cT^{1.6}} + \frac{4.2\,cRT_c^{5.2}}{P_cT^{4.2}}$$

$$\boxed{= \frac{aRTc}{P_c} + \frac{2.6bRT_c^{2.6}}{P_cT^{1.6}} + \frac{5.2\,cRT_c^{5.2}}{P_c\,T^{4.2}} = Z}$$

$$\lim_{p^*\to 0}\int_{P1}^{P^*} Z_{T_1} dP + \int_{P^*}^{P_2} Z_{T_2} dP$$

$$= \lim_{P^*\to 0} Z_{T_1}\cancel{P_*} - Z_{T_1}P_1 + ZP_2 - Z_{T_2}\cancel{P_*}$$

$$\frac{0.109\left(1.987\frac{cal}{gmol\,k}\right)(308.32k)}{60.7atm} + \frac{2.6(-0.422)(1.987)(308.32k)^{2.6}}{60.7atm\,(573.16k)^{1.6}}$$

$$+(5.2)(-0.032)\frac{(1.987)(308.32k)^{5.2}}{60.7atm\,(573.16)^{4.2}} \quad (20atm)(-1). \quad + Z_{T_2}P_2$$

$$= -(1.100113189 \quad -4.10636916 - 0.124226043\ )(20) \ + Z_{T_2}P_2$$

$$= 62.61008909 \qquad + Z_{T_2}P_2$$

$$\left(Z_{T_2}P_2\right) \rightarrow \quad (1.100131\,89 - 2.093867791 - 0.021202019\ )($$

$$= -20.29875841$$

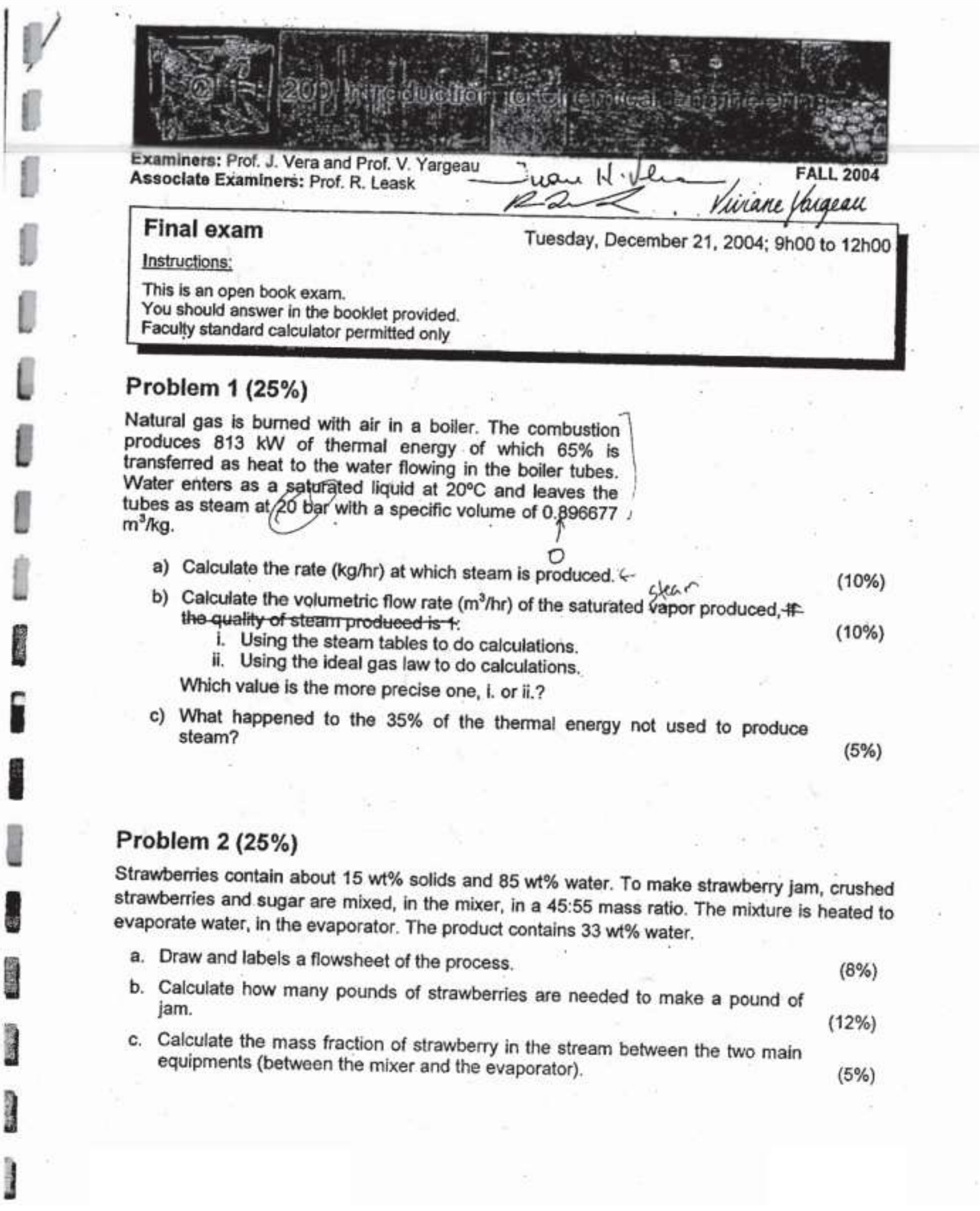
$$62.61008909 - 20.29875841$$

$$= 42.31133068 \text{ cal/gmol}$$

$$\Delta h = 4318.729524\,\frac{cal}{gmol} + 42.31133068\,\frac{cal}{gmol}$$

$$\boxed{= 4361.040855\ cal/gmol}$$

Final



200 Introduction to chemical engineering

Examiners: Prof. J. Vera and Prof. V. Yargeau
Associate Examiners: Prof. R. Leask

Juan H. Vera
Viviane Yargeau

FALL 2004

Final exam

Tuesday, December 21, 2004; 9h00 to 12h00

Instructions:

This is an open book exam.
You should answer in the booklet provided.
Faculty standard calculator permitted only

Problem 1 (25%)

Natural gas is burned with air in a boiler. The combustion produces 813 kW of thermal energy of which 65% is transferred as heat to the water flowing in the boiler tubes. Water enters as a saturated liquid at 20°C and leaves the tubes as steam at 20 bar with a specific volume of 0.896677 m^3/kg.

0

a) Calculate the rate (kg/hr) at which steam is produced. ← (10%)

b) Calculate the volumetric flow rate (m^3/hr) of the saturated steam vapor produced, ~~if the quality of steam produced is 1~~: (10%)
   i. Using the steam tables to do calculations.
   ii. Using the ideal gas law to do calculations.

   Which value is the more precise one, i. or ii.?

c) What happened to the 35% of the thermal energy not used to produce steam? (5%)

Problem 2 (25%)

Strawberries contain about 15 wt% solids and 85 wt% water. To make strawberry jam, crushed strawberries and sugar are mixed, in the mixer, in a 45:55 mass ratio. The mixture is heated to evaporate water, in the evaporator. The product contains 33 wt% water.

a. Draw and labels a flowsheet of the process. (8%)
b. Calculate how many pounds of strawberries are needed to make a pound of jam. (12%)
c. Calculate the mass fraction of strawberry in the stream between the two main equipments (between the mixer and the evaporator). (5%)

Problem 3 (25%)

A heat pump, using a valve as the expansion device, 'pumps' 75000 [btu/hr] of heat from the surroundings and delivers heat into a building. In a Montreal winter day, the temperature of the surroundings is – 15 °C (minus fifteen degrees Celsius) and the temperature inside the building is kept at + 19 °C (plus nineteen degrees Celsius). The pump consumes a power of 5.6 kW. For simplicity, neglect the pressure drop in pipes, assume that all heat exchange between the working fluid and the surroundings occurs either in the evaporator or in the condenser, and consider that the compressor operates adiabatically. With these assumptions, calculate;

a) the enthalpy change per cycle of t[illegible] (5%)

b) the heating power delivered by the [illegible] ilding; (5%)

c) the COP of the heat pump; (5%)

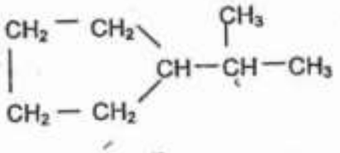
d) the COP of a reversible heat pum[illegible] ump) operating between the same surroundings temperature [illegible] temperature inside the building; and (5%)

e) the second law efficiency of the heat pump. (5%)

Hint: Be very careful with the signs for heat and work.

Problem 4 (25%)

Isopropyl cyclopentane has the structure shown here:



The molecular weight of isopropyl cyclopentane is 122.22 and its normal boiling point is 126.4 °C.

a) Estimate the parameters a and b for the Redlich and Kwong cubic equation of state for this compound. Give the value of a in [atm $(cm^3/gmol)^2$] and the value of b in [cm^3/gmol]. (5%)

b) Knowing the normal boiling point of isopropyl cyclopentane (given above) and that at 16.3°C its vapor pressure is 10 mmHg, estimate the heat of vaporization in [cal/gmol] at 80°C. Use the critical constants given in part c and assume valid the following relation for the vapor pressure at saturation: (10%)

$$\log_{10} P^s = A - \frac{B}{T}$$ with P^s in mmHg and T in Kelvins

c) What is the driving force by which the isopropoyl cyclopentane forms two phases, a liquid and a gas in equilibrium? (4%)

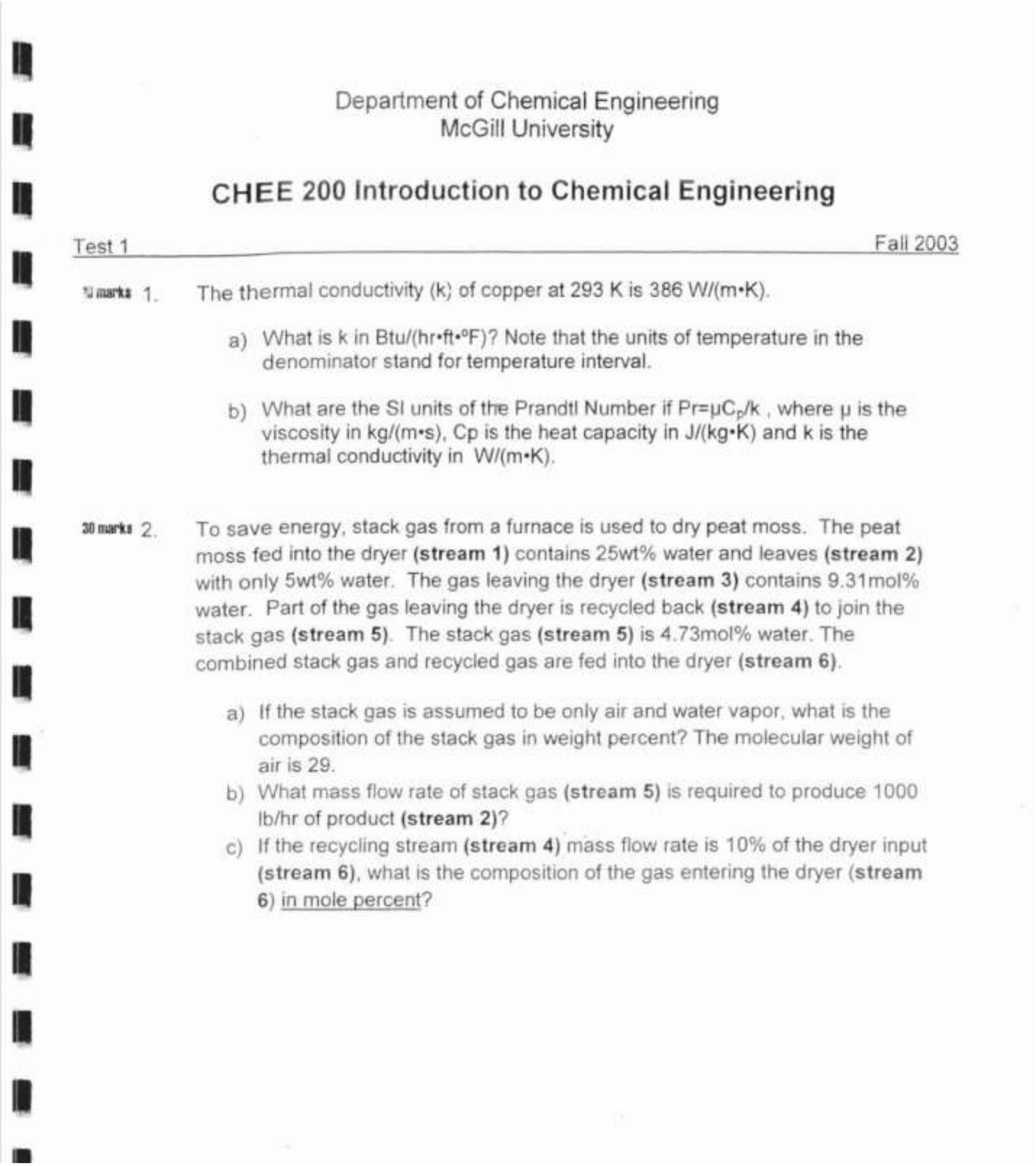
d) Describe the role of energy and entropy in phase equilibria? (6%)

Bonus problem (5 points)

In a maximum of four lines, explain using words not only equations, why $C_p \neq C_v$ for gases.

2003

Test 1



Department of Chemical Engineering
McGill University

CHEE 200 Introduction to Chemical Engineering

Test 1 Fall 2003

10 marks 1. The thermal conductivity (k) of copper at 293 K is 386 W/(m•K).

a) What is k in Btu/(hr•ft•°F)? Note that the units of temperature in the denominator stand for temperature interval.

b) What are the SI units of the Prandtl Number if $Pr=\mu C_p/k$, where μ is the viscosity in kg/(m•s), Cp is the heat capacity in J/(kg•K) and k is the thermal conductivity in W/(m•K).

30 marks 2. To save energy, stack gas from a furnace is used to dry peat moss. The peat moss fed into the dryer **(stream 1)** contains 25wt% water and leaves **(stream 2)** with only 5wt% water. The gas leaving the dryer **(stream 3)** contains 9.31mol% water. Part of the gas leaving the dryer is recycled back **(stream 4)** to join the stack gas **(stream 5)**. The stack gas **(stream 5)** is 4.73mol% water. The combined stack gas and recycled gas are fed into the dryer **(stream 6)**.

a) If the stack gas is assumed to be only air and water vapor, what is the composition of the stack gas in weight percent? The molecular weight of air is 29.

b) What mass flow rate of stack gas **(stream 5)** is required to produce 1000 lb/hr of product **(stream 2)**?

c) If the recycling stream **(stream 4)** mass flow rate is 10% of the dryer input **(stream 6)**, what is the composition of the gas entering the dryer (**stream 6**) in mole percent?

MIDTERM 1 SOLUTIONS

① $K = 386 \frac{W}{m \cdot K}$

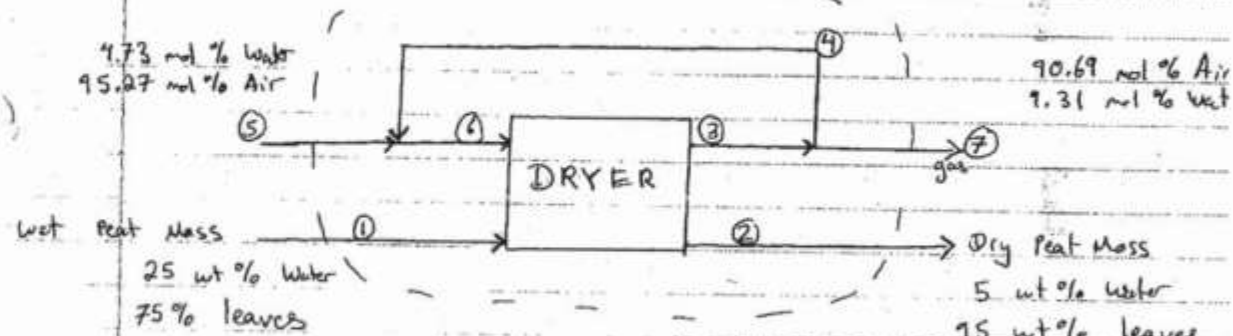
a) $386 \frac{J}{s \cdot m \cdot K} \times \frac{9.48 \times 10^{-4}\ Btu}{1\ J} \times \frac{3600\ s}{1\ hr} \times \frac{0.3048\ m}{1\ ft} \times \frac{1}{1.8}$

$= 223 \frac{Btu}{hr \cdot ft \cdot °F}$ ✓

b) DIMENSIONLESS

$P_r = \frac{\mu C_p}{K} = \frac{\left(\frac{kg}{m \cdot s}\right) \cdot \left(\frac{J}{kg \cdot k}\right)}{\left(\frac{J}{s \cdot m \cdot K}\right)}$ = all units cancel!

②



Assume

1) No chemical reactions
2) Steady state

a) Stack gas ⑤ → assume basis of 100 moles:

so 4.73 mol water $\times 18 \frac{g}{mol} = 85.14$ g
95.27 mol air $\times 29 \frac{g}{mol} = 2762.83$ g

2847.97 g

Air wt % $= \frac{2762.83}{2847.97} = 0.9701 = 97.01\%$ ✓

Water wt % $= 100 - 97.01\% = 2.99\%$ ✓

17

b) <u>Mass balances</u> Define $m_2 = 1000 \frac{lb}{hr}$

<u>Total</u>: $m_1 + m_5 = m_7 + m_2$

$m_1 + m_5 = m_7 + 1000 \frac{lb}{hr}$ (1)

<u>Leaves</u>: $0.75\, m_1 = 0.95\, m_2 = 0.95\,(1000 \frac{lb}{hr})$

$$\boxed{m_1 = 1266.\bar{6} \frac{lb}{hr}}$$

<u>Air</u>: → need weight % of stream 7 (or 3)

100 mol basis

9.31 mol Water × 18 g/mol = 167.58 g ⇒ % Water = 5.99

90.69 mol Air × 29 g/mol = 2630.01 g   % Air = 94.01

2797.59

So,

$0.9701\, m_5 = 0.9401\, m_7$ <u>Plug</u> this into (1)

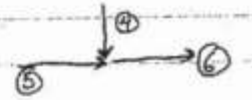
$m_7 = 1.0319\, m_5$

$1266.\bar{6} + m_5 = 1.0319\, m_5 + 1000$

$$\boxed{m_5 = 8356.4 \frac{lb}{hr}} \text{ so } \boxed{m_7 = 8623.06 \frac{lb}{hr}}$$

c) $m_4 = 0.1\, m_6$

Use system II ⇒



plug in

Total balance: $m_5 + m_4 = m_6$

$8356.4 + 0.1\, m_6 = m_6$

$$\boxed{m_6 = 9284.\bar{8} \frac{lb}{hr}}$$

$$\boxed{m_4 = 928.48 \frac{lb}{hr}}$$

<u>Water</u> $0.0299\, m_5 + 0.0599\, m_4 = x_{6w}\, m_6$

$x_{6w} = 0.032896$

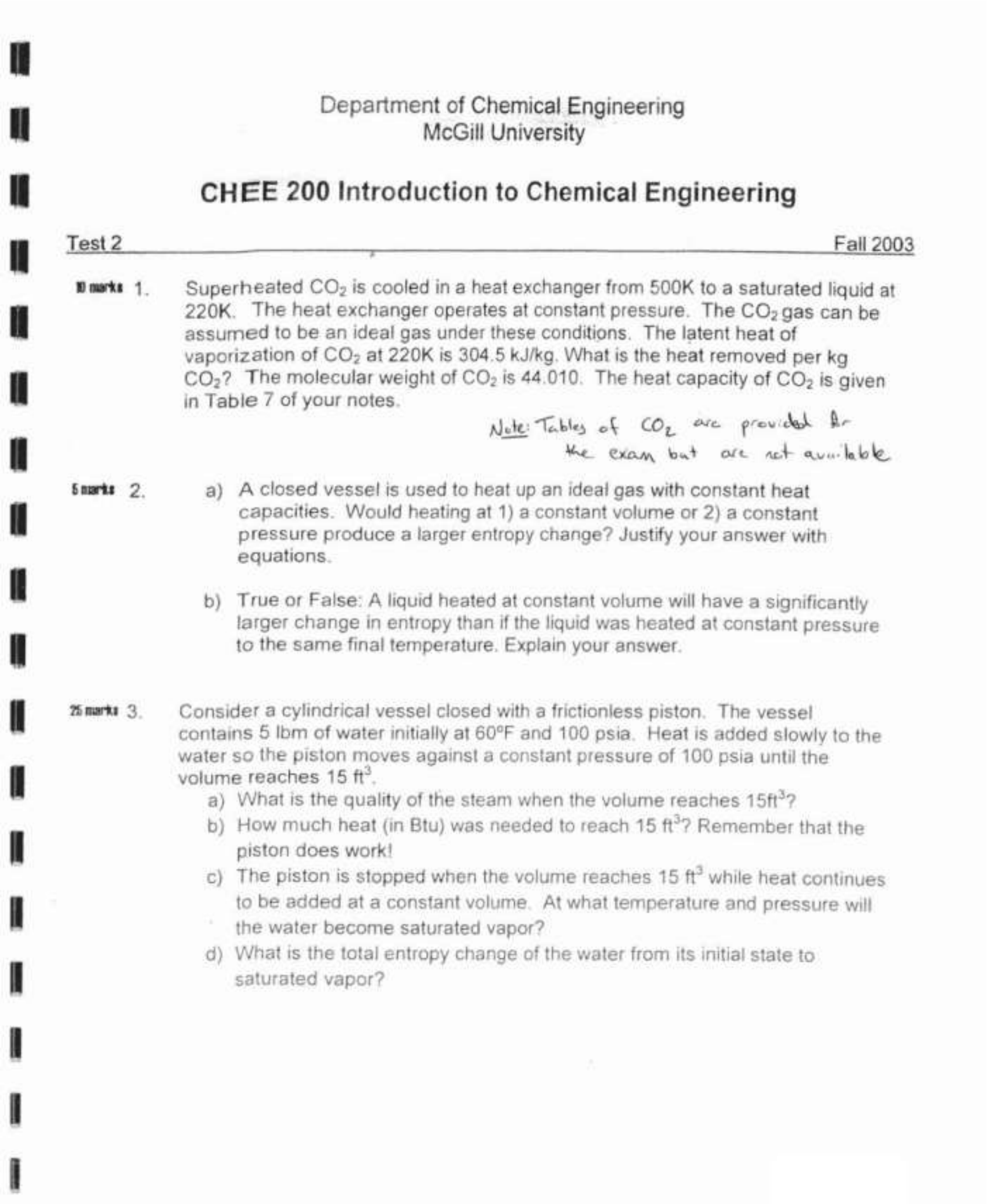
Assume 1 lbm stack gas

air 0.967104 lbm → 0.033348 moles → 94.8 % Air

water 0.032596 lbm → 0.001826 mols → 5.2 % Water

0.0351796

Test 2



Department of Chemical Engineering
McGill University

CHEE 200 Introduction to Chemical Engineering

Test 2 Fall 2003

10 marks 1. Superheated CO_2 is cooled in a heat exchanger from 500K to a saturated liquid at 220K. The heat exchanger operates at constant pressure. The CO_2 gas can be assumed to be an ideal gas under these conditions. The latent heat of vaporization of CO_2 at 220K is 304.5 kJ/kg. What is the heat removed per kg CO_2? The molecular weight of CO_2 is 44.010. The heat capacity of CO_2 is given in Table 7 of your notes.

Note: Tables of CO_2 are provided for the exam but are not available

5 marks 2.

a) A closed vessel is used to heat up an ideal gas with constant heat capacities. Would heating at 1) a constant volume or 2) a constant pressure produce a larger entropy change? Justify your answer with equations.

b) True or False: A liquid heated at constant volume will have a significantly larger change in entropy than if the liquid was heated at constant pressure to the same final temperature. Explain your answer.

25 marks 3. Consider a cylindrical vessel closed with a frictionless piston. The vessel contains 5 lbm of water initially at 60°F and 100 psia. Heat is added slowly to the water so the piston moves against a constant pressure of 100 psia until the volume reaches 15 ft^3.

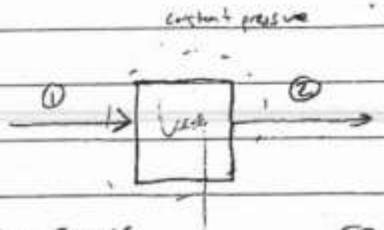
a) What is the quality of the steam when the volume reaches 15ft^3?

b) How much heat (in Btu) was needed to reach 15 ft^3? Remember that the piston does work!

c) The piston is stopped when the volume reaches 15 ft^3 while heat continues to be added at a constant volume. At what temperature and pressure will the water become saturated vapor?

d) What is the total entropy change of the water from its initial state to saturated vapor?

①



Assume
- ideal gas CO_2
- constant pressure
- ~~no work~~
- adiabatic, no heat loss

superheated ① $T_1 = 500 K$

② saturated liquid

$T_2 = 220\ K$

$\dot{m}_1 = \dot{m}_2 = \dot{m}$

$\therefore \Delta e_k = 0$

at 220K, $\Delta h^s = 304.5\ \frac{kJ}{kg}$

$$(h + \underset{0}{\cancel{e_p}} + \underset{0}{\cancel{e_k}})_2 \dot{m} - (h + \underset{0}{\cancel{e_p}} + \underset{0}{\cancel{e_k}})_1 \dot{m} = Q - \underset{0}{\cancel{W}}$$

$$\Delta h\, \dot{m} = Q$$

h_1 from ~~steam~~ tables, (superheated)

$$\Delta h = \int_{T_1}^{T_2} c_p\, dT \quad + \quad \Delta h^s$$

10/10

$$= \int_{500}^{220} \left(10.57 + 2.10\times10^{-3}T - \frac{2.06\times10^5}{T^2}\right) dT$$

$$= (10.57)(220-500) + 2.10\times10^{-3}\frac{T^2}{2}\Big|_{500}^{220} + \frac{2.06\times10^5}{T}\Big|_{500}^{220}$$

$$= -2959.6 \quad -211.68 \quad -2.06\times10^5\left(-\frac{1}{220} + \frac{1}{500}\right)$$

$$= -3171.28 + 524.56$$

$$= -2646.916364\ \frac{cal}{mol\cdot} \quad + \quad \Delta h^s$$

$$\rightarrow -2646.916364\ \frac{cal}{\cancel{mol}} \times \frac{1\ mol}{44.010\ g} = -60.1435211\ \frac{cal}{g} \times \frac{1000\ g}{1\ kg} \times \frac{4.184}{c}$$

$$304.5\ \frac{kJ}{kg} \qquad = -251.8088941\ \frac{kJ}{kg}$$

$$\Delta h = -251.8088941 - \Delta h^s = -556.3088941\ \frac{kJ}{kg} \longrightarrow \boxed{-556\ \frac{kJ}{k}}$$

45

② a) $\Delta S_p = m\int_{T_1}^{T_2} \frac{c_p^*}{T}\, dT$

$\Delta S_v^* = m\int_{T_1}^{T_2} \frac{c_v^*}{T}\, dT$

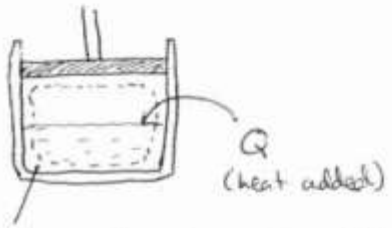
$c_p^* > c_v^*$ so heating at constant pressure!

b) FALSE.

$\delta s = \frac{\delta Q}{T}$

For liquids, $c_p \approx c_v$ (only a difference of R)

③



Assume:
- frictionless piston
- Piston does work!
- constant pressure
- $\Delta e_p = \Delta e_k = 0$

5 lbm water at $T_i = 60°F$, $P_i = 100$ psia > subcooled

At final stage, $P_f = 100$ psia

$V = 15\ ft^3$

a) Final specific volume is $\frac{15\ ft^3}{5\ lbm} = 3\ \frac{ft^3}{lbm} = V_{system}$

From saturated steam tables,

fluid $v_f\,(100\text{ psia}) = 0.017740\ \frac{ft^3}{lbm}$

gas $v_g\,(100\text{ psia}) = 4.4310\ \frac{ft^3}{lbm}$

$V_{sys} = (1-x)v^f + x\,v^g$

$3\ \frac{ft^3}{lbm} = (1-x)(0.017740) + x\,(4.4310)$

$x = 0.6757$ so quality $= \boxed{67.6\%}$

b) $Q = ?$

$\Delta U + \cancel{\Delta e_p}^{0} + \cancel{\Delta e_k}^{0} = Q - W$

$\Delta U = Q - W$

Since $\Delta h = \Delta u + \Delta(PV)$,

$$\Delta h - \Delta(PV) = Q - \int P\,dV$$

$$\Delta h - \cancel{P\Delta V} - \underset{0}{\cancel{V\Delta P}} = Q - \cancel{\int P\,dV}$$

$$\dot{m}\,\Delta h = Q$$

From steam tables

$h^{\ell}(327.82\,°F,\ 100\ \text{psia}) = 298.5\ \frac{Btu}{lbm}$

$h^{\ell v}(327.82\,°F,\ 100\ \text{psia}) = 888.6\ \frac{Btu}{lbm}$

$$h_{sys} = h^{\ell} + x\,h^{\ell v}$$

$$= 298.5 + (0.676)(888.6) = 899.19\ \frac{Btu}{lbm}$$

$$Q = m \cdot h = 899.19\ \frac{Btu}{\cancel{lbm}} \times 5\ \cancel{lbm} = 4495.97\ Btu$$

$$= 4500\ Btu$$

c)

T ?
P ?

V is constant, so since there is only vapor,

$$v^{vap} = 3\ \frac{ft^3}{lbm}$$

From the steam tables, $T(3.0139\ \frac{ft^3}{lbm}) = 358.43\ °F$

$T(2.8336\ \frac{ft^3}{lbm}) = 363.55\ °F$

- Interpolating, we get $\boxed{T = 358.82\ °F}$

$P(3.0139\ \frac{ft^3}{lbm}) = 150\ \text{psia}$

$P(2.8336\ \frac{ft^3}{lbm}) = 160\ \text{psia}$

- Interpolating, we get $\boxed{P = 151\ \text{psia}}$

d) Assume properties of subcooled liquid @ (100 psia, 60°F equal to the properties of saturated liquid @ 60°F

$\therefore\ s^{\ell}(60°F) = 0.0555\ \frac{Btu}{lb \cdot K}$

@ saturated vapor stage,

$s^{vap}(3.0139\ \frac{ft^3}{lbm}) = 1.5695\ \frac{Btu}{lb \cdot K}$

$s^{vap}(2.8336\ \frac{ft^3}{lbm}) = 1.5641\ \frac{Btu}{lb \cdot K}$

4

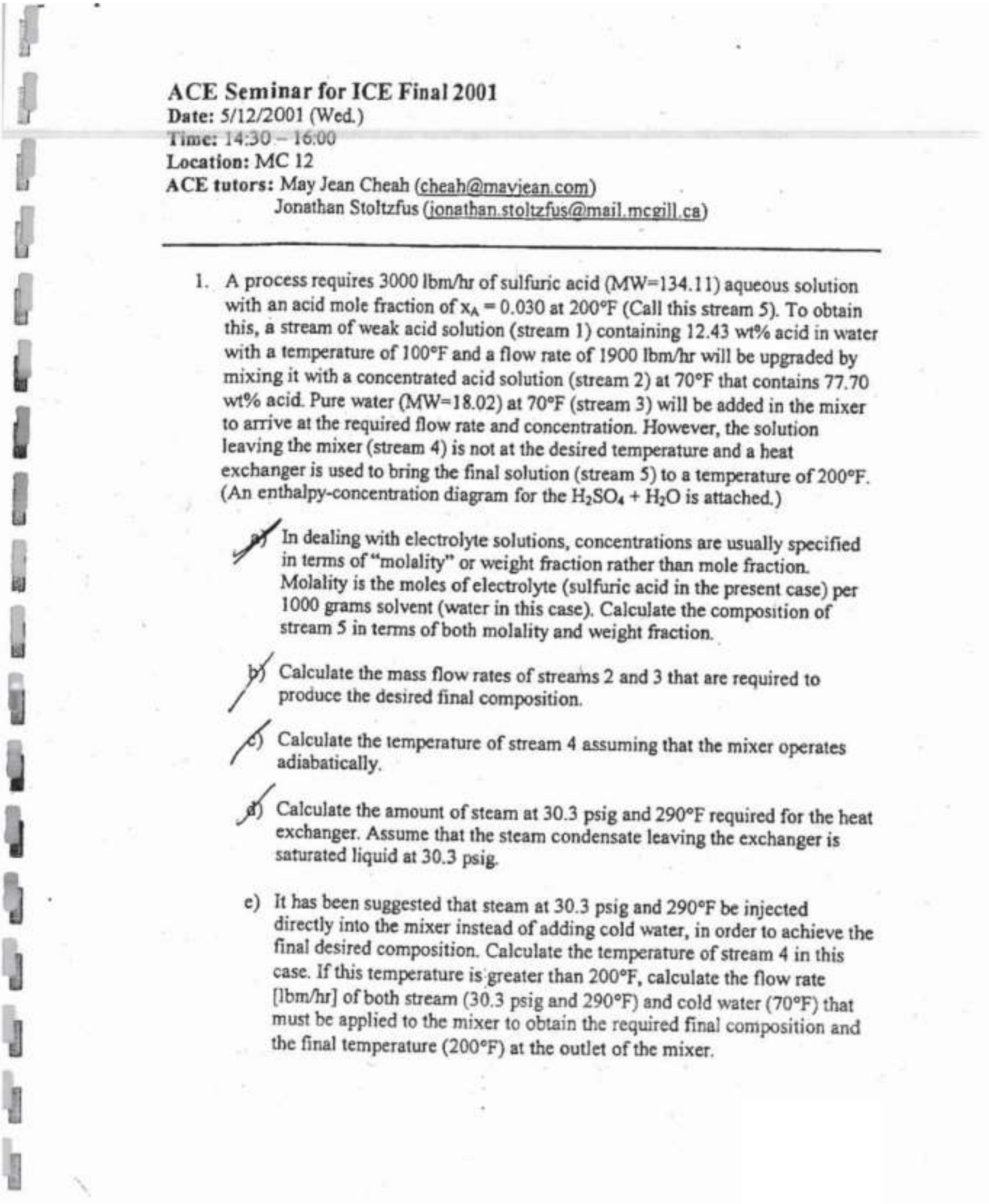
Interpolating, we get $s^{vap} = 1.5690 \ \frac{\text{Btu}}{\text{lb-K}}$

$$\therefore \ \Delta s = 1.5690 - 0.0555 = 1.5136 \ \frac{\text{Btu}}{\text{lb}\cdot\text{K}} = \boxed{1.51 \ \frac{\text{Btu}}{\text{lb}\cdot\text{K}}}$$

2002

2001

Final



ACE Seminar for ICE Final 2001
Date: 5/12/2001 (Wed.)
Time: 14:30 – 16:00
Location: MC 12
ACE tutors: May Jean Cheah (cheah@mayjean.com)
Jonathan Stoltzfus (jonathan.stoltzfus@mail.mcgill.ca)

---

1. A process requires 3000 lbm/hr of sulfuric acid (MW=134.11) aqueous solution with an acid mole fraction of $x_A = 0.030$ at 200°F (Call this stream 5). To obtain this, a stream of weak acid solution (stream 1) containing 12.43 wt% acid in water with a temperature of 100°F and a flow rate of 1900 lbm/hr will be upgraded by mixing it with a concentrated acid solution (stream 2) at 70°F that contains 77.70 wt% acid. Pure water (MW=18.02) at 70°F (stream 3) will be added in the mixer to arrive at the required flow rate and concentration. However, the solution leaving the mixer (stream 4) is not at the desired temperature and a heat exchanger is used to bring the final solution (stream 5) to a temperature of 200°F. (An enthalpy-concentration diagram for the $H_2SO_4 + H_2O$ is attached.)

   a) In dealing with electrolyte solutions, concentrations are usually specified in terms of "molality" or weight fraction rather than mole fraction. Molality is the moles of electrolyte (sulfuric acid in the present case) per 1000 grams solvent (water in this case). Calculate the composition of stream 5 in terms of both molality and weight fraction.

   b) Calculate the mass flow rates of streams 2 and 3 that are required to produce the desired final composition.

   c) Calculate the temperature of stream 4 assuming that the mixer operates adiabatically.

   d) Calculate the amount of steam at 30.3 psig and 290°F required for the heat exchanger. Assume that the steam condensate leaving the exchanger is saturated liquid at 30.3 psig.

   e) It has been suggested that steam at 30.3 psig and 290°F be injected directly into the mixer instead of adding cold water, in order to achieve the final desired composition. Calculate the temperature of stream 4 in this case. If this temperature is greater than 200°F, calculate the flow rate [lbm/hr] of both stream (30.3 psig and 290°F) and cold water (70°F) that must be applied to the mixer to obtain the required final composition and the final temperature (200°F) at the outlet of the mixer.

2. Ethylbenzene (MW=106.17) enters a water-cooled compressor at 2.0 atm and 180°C, with a flow rate of 782 moles per hour, and leaves as saturated vapour at 15.0 atm. The power input is 4.26kW. The vapour leaving the compressor is condensed at constant pressure to produce saturated liquid, which enters a pump having an efficiency of 50%. The pressure at the outlet of the pump is 20.0atm. The density of liquid ethylbenzene is 0.867 g/cc.

   You may use the following estimated ideal gas heat capacity equation.

   C_p^*(cal/mol K)= $-7.6711+15.368\times10^{-2}T-0.9283\times10^{-4}T^2+0.0213\times10^{-6}T^3$ (T in K)

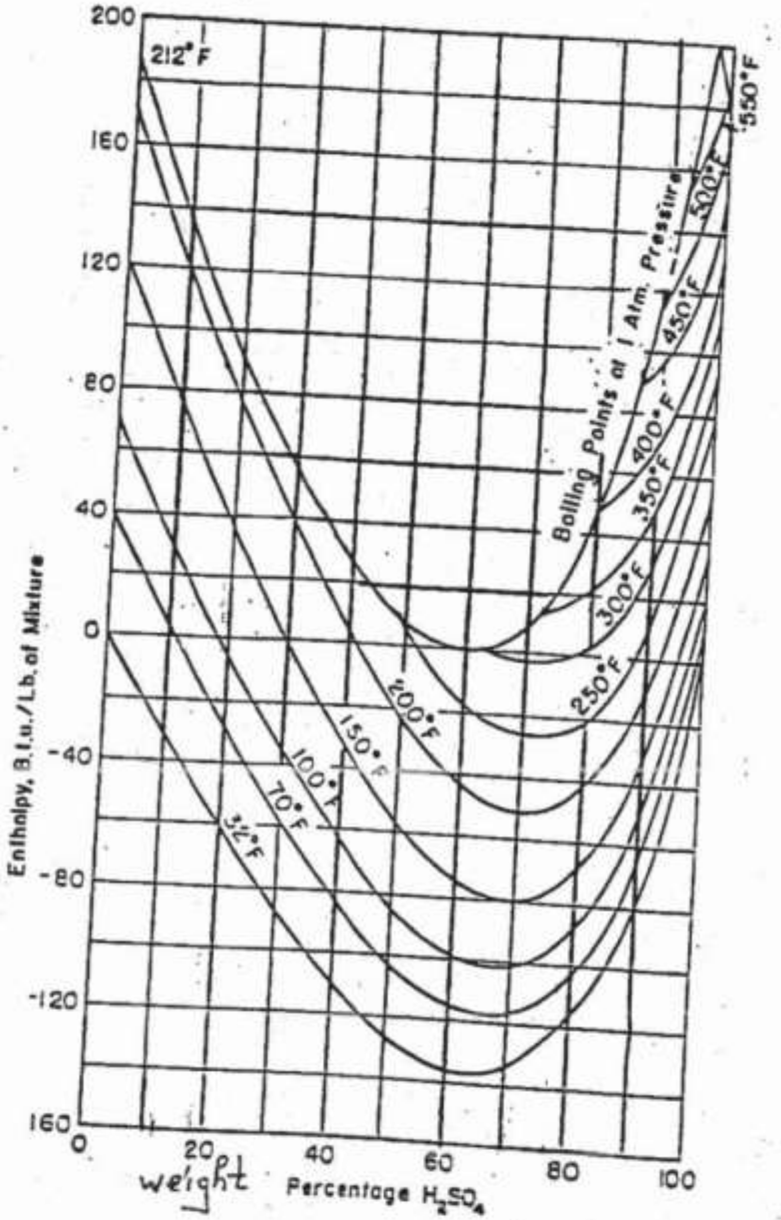
   a) What is the cooling rate for the compressor (W)?

   b) What is the heat transfer rate for the condenser (kW)?

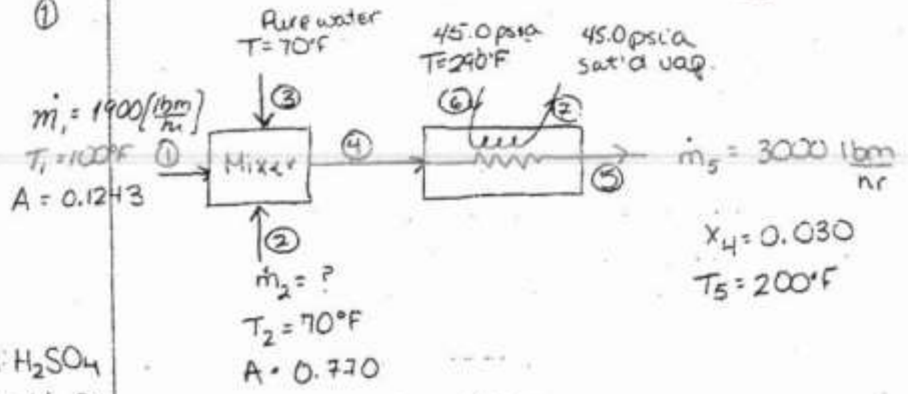
   c) What is the power requirement of the pump (W)?

   d) Explain how the estimated coefficients in the heat capacity equation were obtained and demonstrate the procedure by calculating the first constant.

Note: Question 1 in the seminar was the Question 1 in Final 2000. Question 2 in the seminar was Question 3 in Final 2000. These questions were written by Professor J.M. Dealy and Professor J.H. Vera.


Enthalpy, B.t.u./Lb. of Mixture
200
160
120
80
40
0
-40
-80
-120
160
0
20
40
60
80
100
weight
Percentage H_2SO_4
212°F
550°F
500°F
450°F
400°F
350°F
300°F
250°F
200°F
150°F
100°F
70°F
32°F
Boiling Points at 1 Atm. Pressure

①



A: H_2SO_4
W: H_2O

a) Temporary basis of 1 mol of sol'n in stream 5

$n_{5A} = 0.03 \Rightarrow m_{5A} = n_{5A} \cdot mW_A = 4.0233$ lbm

$n_{5W} = 0.97 \Rightarrow m_{5W} = n_{5W} \cdot mW_A = 17.4794$ lbm

weight fraction

-of A $= \dfrac{4.0233}{4.0233 + 17.4794} = 0.1871$

-of W $= 0.8129$

Note:
MW = molec. wt.
$mW_A = 134.11$
$mW_W = 18.02$

Molality
Temp. basis: 1000 g W

$$\frac{M_A}{M_A + 1000} = 0.1871$$

$0.8129\, m_A = 187.1$

$m_A = 230.164$ g

$n_A = \dfrac{230.164\,[g]}{134.11\,[\frac{g}{g\text{-mol}}]} = 1.72$ mol

$\therefore$ molality $= \dfrac{1.72}{1000} \left[\dfrac{\text{mol } H_2SO_4}{\text{g } H_2O}\right]$

1b.

$\dot{m}_2 = ?$

$\dot{m}_3 = ?$

basis 1 hr.

<u>mixer</u>

$m_4 = m_5 = 3000$ [lbm]

$m_1 + m_2 + m_3 = m_4$

$m_2 + m_3 = 1100$ [lbm] ①

mass balance on A:

$0.1243(1900) + 0.777\dot{m}_2 + 0\cdot m_3 = 0.1871(3000)$

$\dot{m}_2 = 418.443$

$\therefore \dot{m}_2 = 418.4 \left[\frac{lbm}{hr}\right]$ ②

② into ①

$\dot{m}_3 = 1100 - 418.4 = 681.6 \left[\frac{lbm}{hr}\right]$

c) $T_4 = ?$

Energy Balance from chart: $h_1 \simeq 20$ [Btu/lbm]

$H_1 + H_2 + H_3 = H_4$

$h_2 \simeq -107$ [Btu/lbm]

$h_3 \simeq 40$ [Btu/lbm]

$H_4 = (20)(1900) + (-107)(418.4) + (40)(681.6)$

$H_4 = 20495.2$ [Btu]

$h_4 = \frac{H_4}{m_4 = 3000 lb}$

$= 6.832$

from chart

$T_4 \simeq 120°F$

d) $\dot{m}_6 =$

$h_4 = 6.832 \left[\frac{Btu}{lbm}\right]$

from chart; $h_5 \simeq 90$ [Btu/lbm]

$\Delta h = h_5 - h_4 = 83.17$ [Btu/lbm]

$\Delta H = 83.17(3000) = 249\,505$ [Btu]

Note: wt. fraction of stream 4 = wt. fraction of stream 5

Note $m_6 = m_7$

$H_7 - H_6 = -249\,505$

$(h_7 - h_6)m_6 = -249505$

from steam tables:

$h_6 = 1180.20$ [Btu/lbm]

$h_7 = 243.49$ [Btu/lbm]

$(243.49 - 1180.20) m_6 = -249505$

$\therefore m_6 = 266.4$

$\dot{m}_6 = 266.4$ [lbm/hr]

steam streams

$\Delta h + \cancel{\Delta E_p}^{0} + \cancel{\Delta E_k}^{0} = q - \cancel{w_s}^{0}$

$\Delta h = q$

−ve ↑ +ve

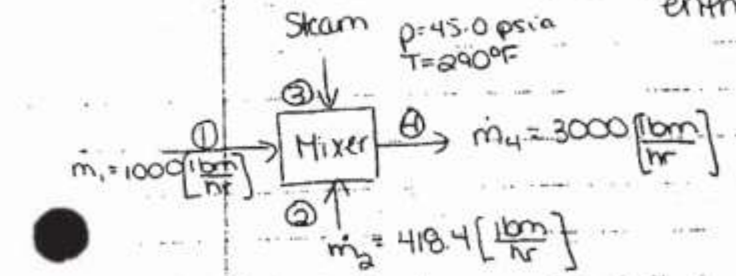
$h_7 < h_6$

e) $H_2SO_4 + H_2O$ stream : $\Delta h + \cancel{\Delta E_p}^{0} + \cancel{\Delta E_k}^{0} = q - \cancel{w_s}^{0}$

$\Delta h = q$

↑ +ve ↑ +ve heat entering system

enthalpy of stream 5 > stream 4



Basis : 1 hr

$m_{3\,steam} = \dot{m}_{3\,water} = 681.6$ (lbm/hr)

because desired final conc. is the same..

BUT do we have the desired temp, T_4?

$H_1 + H_2 + H_3 = H_4$

$H_4 = 20(1900) + 418.4(-107) + 681.6(1180.2)$

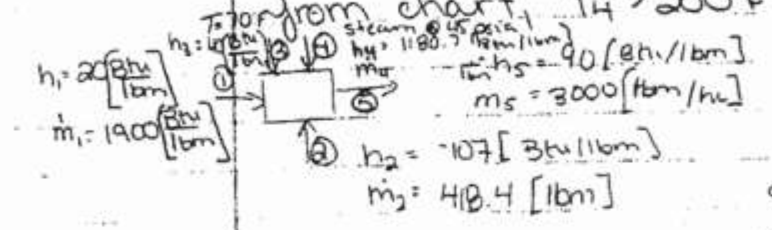
$= 842736$ [BTU]

$h_4 = 280.9$ [Btu/lbm]

from chart, $T_4 > 200$°F

→ T = 200°F
→ conc. in w

(Desired $h_4 = 90$ [Btu/lbm]



$\dot{m}_3 + \dot{m}_4 = 681.6$ [lbm] ①

$H_1 + H_2 + H_3 + H_4 = H_5$

$20(1900) + (-107)(418.4) + m_3(40) + m_4(1180.2) = 90(3000)$ ... ②

solving 1 & 2:

$\dot{m}_4 = 219$ [lbm/hr]

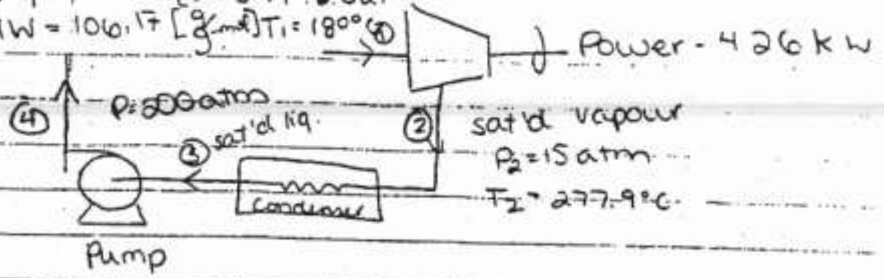
$\dot{m}_3 = 463$ [lbm/hr]

Given:

ρ liq'd = 0.867 $\left[\frac{g}{cm^3}\right]$ $\dot{n}$ = 782 $\left[\frac{mol}{hr}\right]$

P_1 = 2.0 atm

MW = 106.17 $\left[\frac{g}{mol}\right]$ T_1 = 180°



η = 50%

$C_p^* \left[\frac{cal}{mol\,K}\right] = -7.6711 + 15.368\times10^{-2}T - 0.9283\times10^{-4}T^2 + 0.0213\times10^{-6}T^3$ (T i

a) Sys. compressor $\boxed{Q=}$

Energy Balance

$\Delta h + \cancel{\Delta E_p}^{0} + \cancel{\Delta E_k}^{0} = q - W_s$

$q = \Delta h + W_s$

$\log_{10} \underset{\underset{[mmHg]}{\uparrow}}{P^{sat}} = A - \frac{B}{\theta + \underset{\underset{[°C]}{\nwarrow}}{t}}$

A = 6.95719

B = 1424.255

C = 213.206

P_1 = 2.0 atm , t = 164.0°C

$t < T_1$ Ethylbenzene = vapour

P = 760 mmHg , using Antoine

T_b = 136.2°C

since stream ① & ② vapour phase

$\Delta h = \int_{T_1}^{T_2} C_p^* dt + (RT_c)\,\Delta\left(\frac{h^R}{RT_c}\right)$ where $\frac{h^R}{RT_c} = \left(\frac{h^R}{RT_c}\right)^{(0)} + \omega\left(\frac{h^R}{RT_c}\right)^{(1)}$

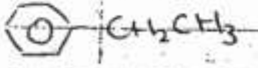
eqn charts

verification: eqn

$T_r > 0.7\,(1+P_r)$

$T_r < 0.7\,(1+P_r)$

T_c = ?



Estimation of critical constant

$=CH$ $-CH_3$

$=C-$

$-CH_2$

$\theta = 0.567 + \Sigma$

$\theta = \frac{T_b}{T_c}$

T_c = 618.6 K

$P_c = \dfrac{M}{(\Sigma\Delta b + 0.34)^2} = 35.97$ atm

verification steps: $T_1 \rightarrow P_1 \rightarrow T_r > 0.6(1 + P_r)$.

Stream 2, using Antoine & $P_2 = 15.0$ atm

$T_2 = 277.9\,°C$

Verification

T_2, P_2, $T_r > 0.6\,(1 + P_r)$

$\therefore$ Use eqns to calculate $\left(\dfrac{h^R}{RT_c}\right)^{(0)}$ & $\left(\dfrac{h^R}{RT_c}\right)^{(1)}$

at T_1, P_1 & T_2, P_2

$$\left(\frac{h^R}{RT_c}\right)^{(0)} = P_r\left(0.083 - \frac{1.097}{T_r^{1.6}}\right) \qquad \omega = -\log(P_r^s)_{T_r = 0.7} - 1.00$$

$$\left(\frac{h^R}{RT_c}\right)^{(1)} = P_r\left(0.139 - \frac{0.894}{T_r^{4.2}}\right)$$

T_1, P_1: $\dfrac{h^R}{RT_c} = -0.148094$ $\qquad T_2, P_2$: $\dfrac{h^R}{RT_c} = -0.67882$

$(RT_c)\ \Delta\left(\dfrac{h^R}{RT_c}\right) = -2729.45\ [J/mol]$ — ①

$$\int_{T_1 = 453.15K}^{T_2 = 551.02K} \dots = 4769.73\,[cal/mol] = 19969.9\,[J/mol] \dots$$

From 1 & 2, $\Delta h = 17240.4$ ... ③

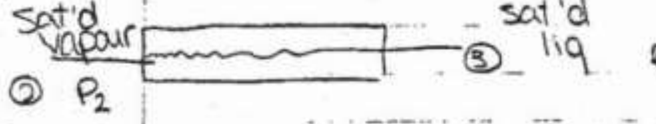
$Q = \Delta h + W_s$ (-ve)

$Q = 17240.4\,[J/mol] \times 782\left[\frac{mol}{hr}\right] \times \frac{1}{3600}\left[\frac{hr}{s}\right] + (-4.26 \times 10^3)$

$= -515\,[W]$

$\therefore$ cooling rate $= 515\,[W]$

b) Condenser



$P_3 = P_2$

$$\Delta h + \cancel{\Delta e_p} + \Delta e_k = q - \cancel{w_s}$$

$$\Delta h = \Delta h^{v}_{T=277.9} = q \qquad (h_3 - h_2)$$

Riedel equation → Watson equation

$$\Delta h^{s}_{T_b} = 8552.62 \left[\frac{cal}{mol}\right] \quad \Big| \quad \Delta h^{s}_{T=277.9} = 5565.36 \left[\frac{cal}{mol}\right]$$

c) $\eta = \dfrac{\Delta P / \rho}{-W_s}$

$P_3 = P_2$
Given P_4

$$-W_s = \frac{P_4 - P_3}{\rho} \times \frac{1}{\eta} = 124.089 \left[\frac{J}{g\text{-}mol}\right]$$

Power requirement of pump
$= -W_s \cdot \dot{n}$ ← flow rate
$= 27.0\ [W]$

d) Rihani & Doraiswamy

$-HC$ ⤢ ⇄
$-C$ ⤢ ⇄
$-\overset{|}{C}H_2$
$-CH_3$

Just calc. for a first estimated coefficient